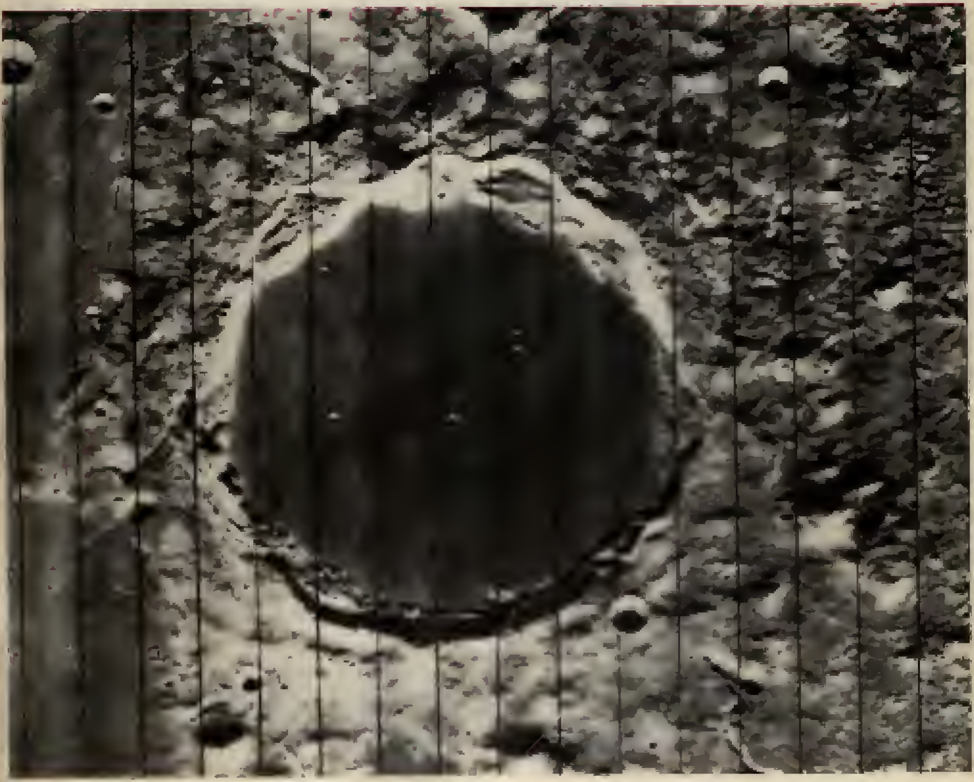
Yearbook of Astronomy 1970



Editor **PATRICK MOORE**

SIDGWICK & JACKSON

1970
Yearbook
of
Astronomy

Edited by
PATRICK MOORE

Sidgwick & Jackson
London

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Editorial

There seems very little to add to what has been said in previous Editorials. Again we owe a tremendous debt to Dr Porter, who has, as before, been responsible for the whole of Part I, apart from the monthly 'comments'. This is the ninth *Yearbook*; throughout Dr Porter has been the mainstay of it.

I am very grateful, too, for our article writers; among our new contributors is that distinguished astronomical writer Dr Joseph Ashbrook, Editor of *Sky and Telescope*, while the British authors will be known to all enthusiasts on this side of the Atlantic as well as to many in the New World.

I must repeat, too, what a pleasant task it is to work with Mr J. S. Knapp-Fisher and his colleagues at Messrs Sidgwick and Jackson.

PATRICK MOORE

Selsey, 1969

Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets, and give details of other astronomical phenomena that may be observed from these latitudes. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis, 21*s*) invaluable, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and readers will also find details of forthcoming events given in the British quarterly periodical *Planetarium* and in the American *Sky and Telescope* which also publishes complete details of all occultations visible in North America.

Important Note

The star charts are drawn, and the notes are, in general, designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude.

The times given on the star charts and in the Monthly Notes are generally given as local times, using the 24-hour clock, the day beginning at midnight. Ignoring small differences of longitude, this local time may be taken as Greenwich Mean Time (G.M.T.) in the British Isles, or as the appropriate Standard Time in other Time Zones. If Summer Time is in use, the clocks will have been advanced by one hour, and this hour must be subtracted from the clock time to give local time.

Readers in Great Britain should note that permanent Summer Time may still be in force. Although this is called 'British Standard Time' it is not, in fact, a true astronomical Standard Time, and *one hour should be deducted from B.S.T. to give G.M.T.* The times of a few events are given in G.M.T., but this is clearly stated in all such cases.

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PART ONE

Events of 1970

Monthly Charts and Astronomical Phenomena

Notes on the Star Charts

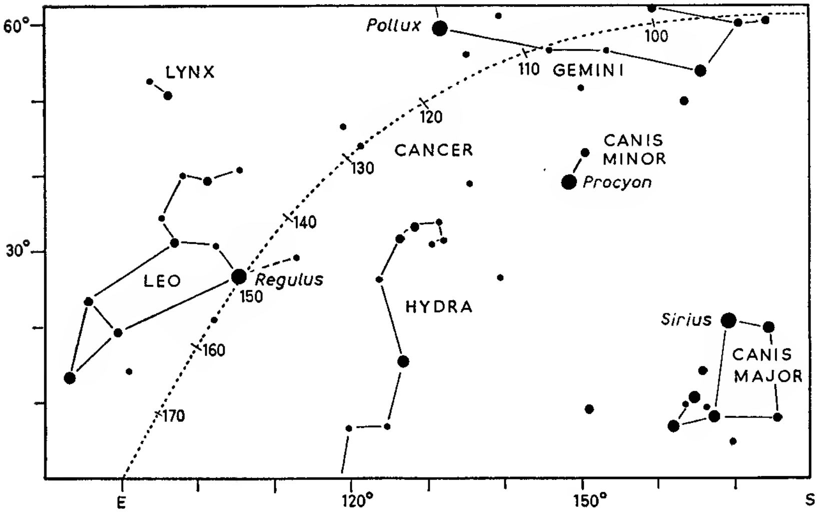
The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 18 to 43 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

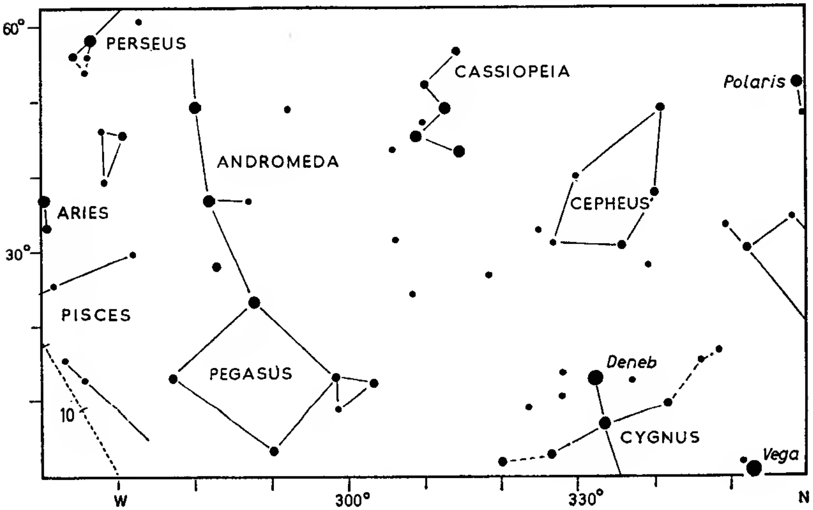
The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of 62½ degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the coverage is 200 degrees in azimuth, from a little north of east

1L

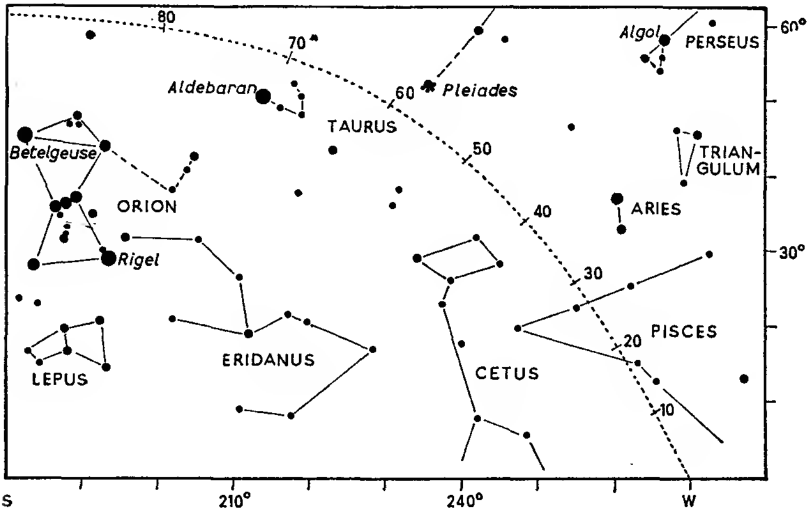
October 6 at 5^h	October 21 at 4^h
November 6 at 3^h	November 21 at 2^h
December 6 at 1^h	December 21 at midnight
January 6 at 23^h	January 21 at 22^h
February 6 at 21^h	February 21 at 20^h

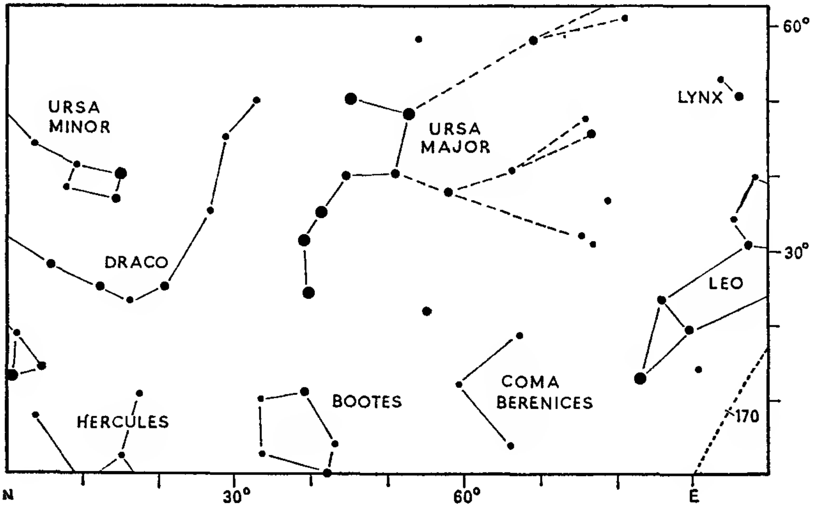




October 6 at	5^{h}	October 21 at	4^{h}
November 6 at	3^{h}	November 21 at	2^{h}
December 6 at	1^{h}	December 21 at	midnight
January 6 at	23^{h}	January 21 at	22^{h}
February 6 at	21^{h}	February 21 at	20^{h}

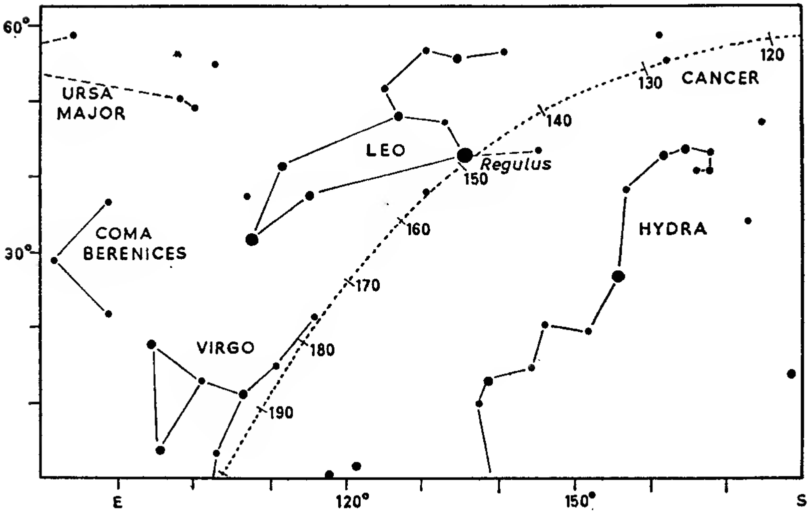
1R

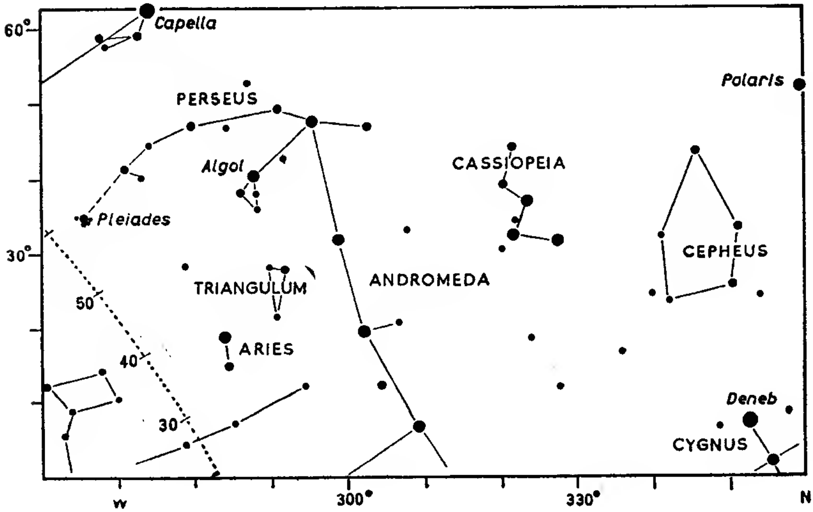




2L

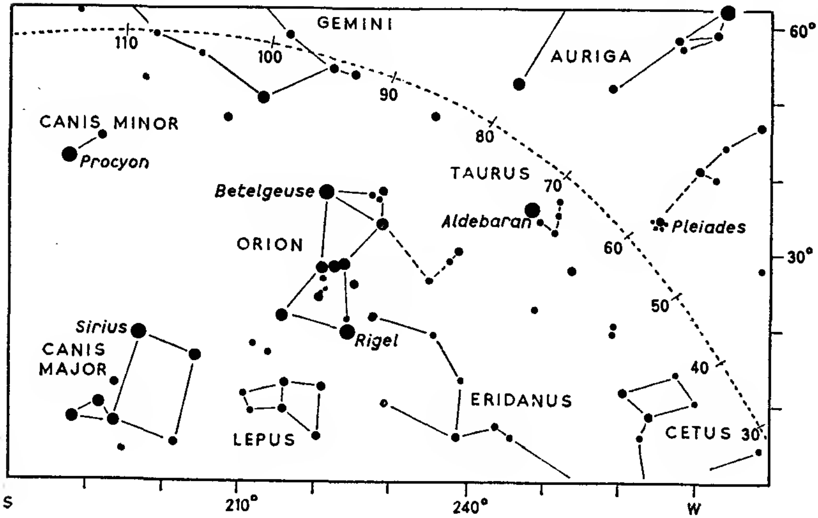
November 6 at 5h	November 21 at 4h
December 6 at 3h	December 21 at 2h
January 6 at 1h	January 21 at midnight
February 6 at 23h	February 21 at 22h
March 6 at 21h	March 21 at 20h

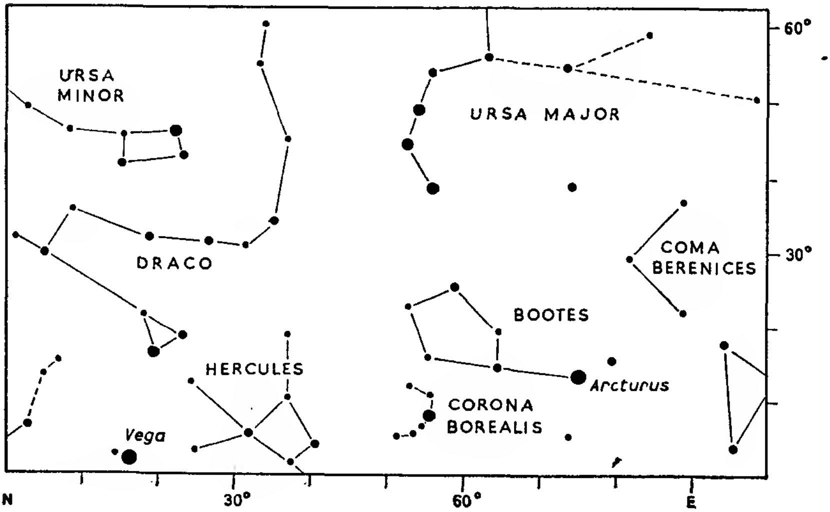




November 6 at 5^h	November 21 at 4^h
December 6 at 3^h	December 21 at 2^h
January 6 at 1^h	January 21 at midnight
February 6 at 23^h	February 21 at 22^h
March 6 at 21^h	March 21 at 20^h

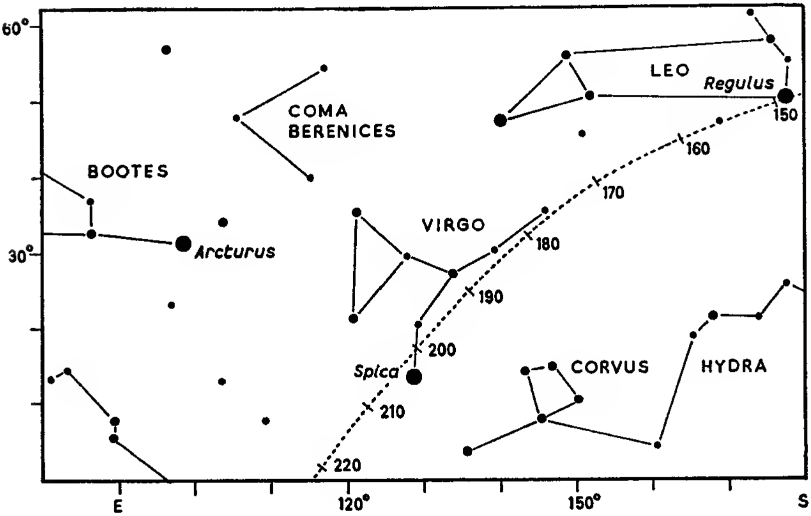
2R

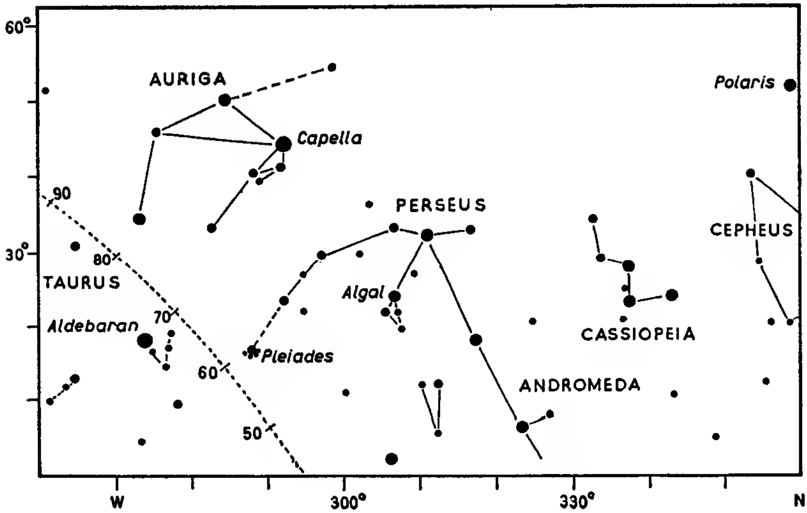




3L

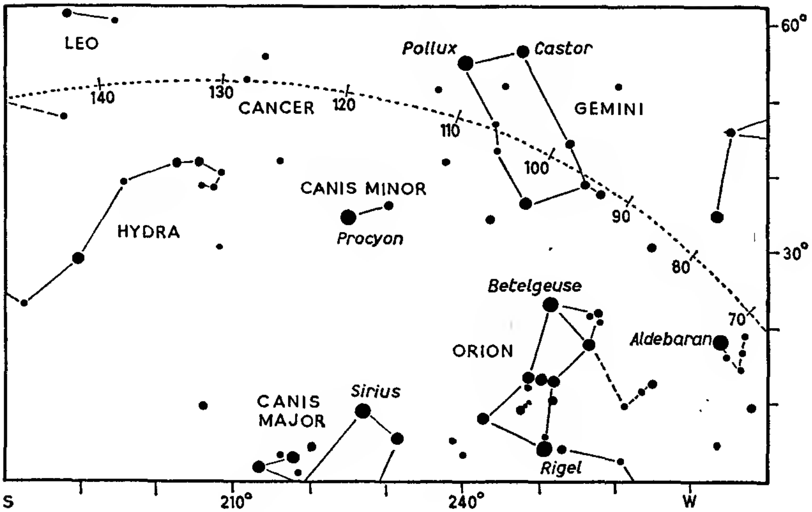
December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h

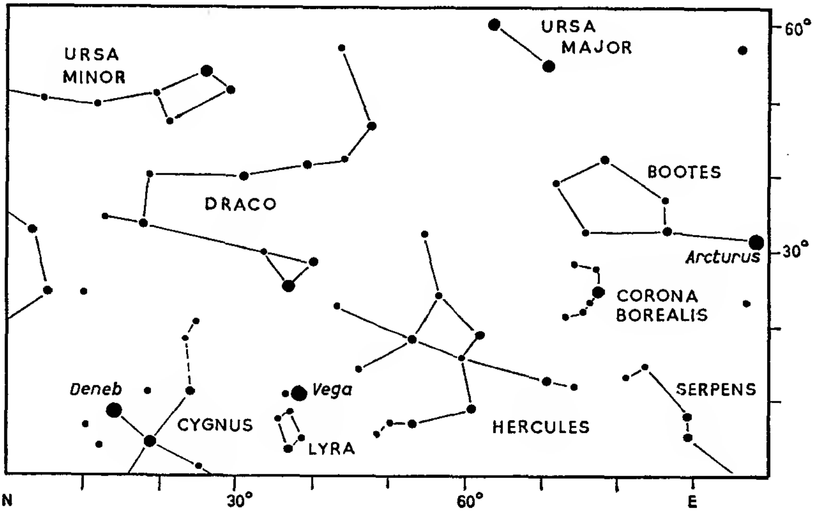




December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h

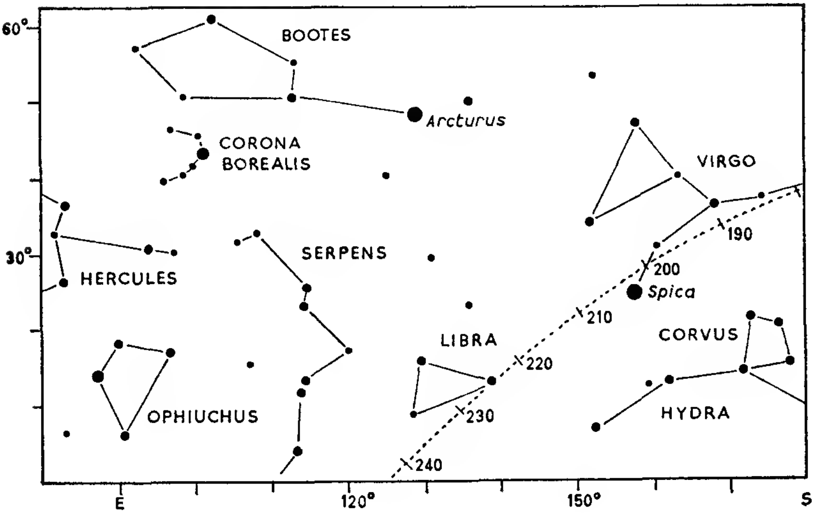
3R

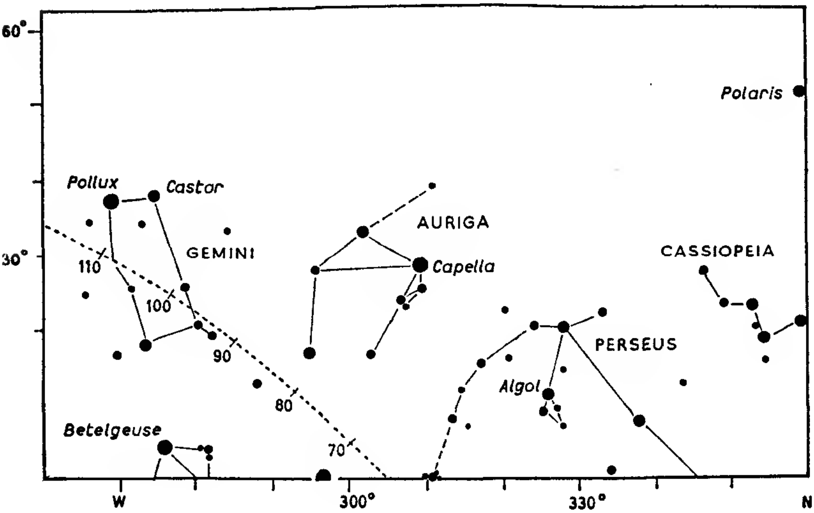




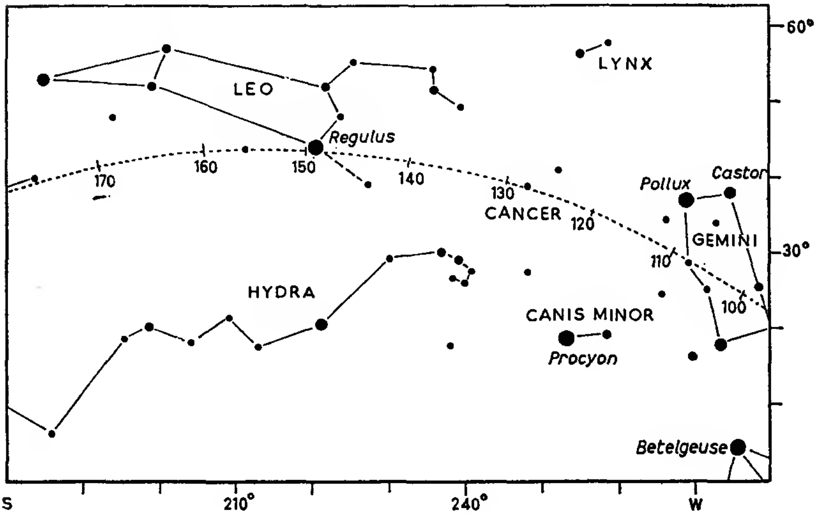
4L

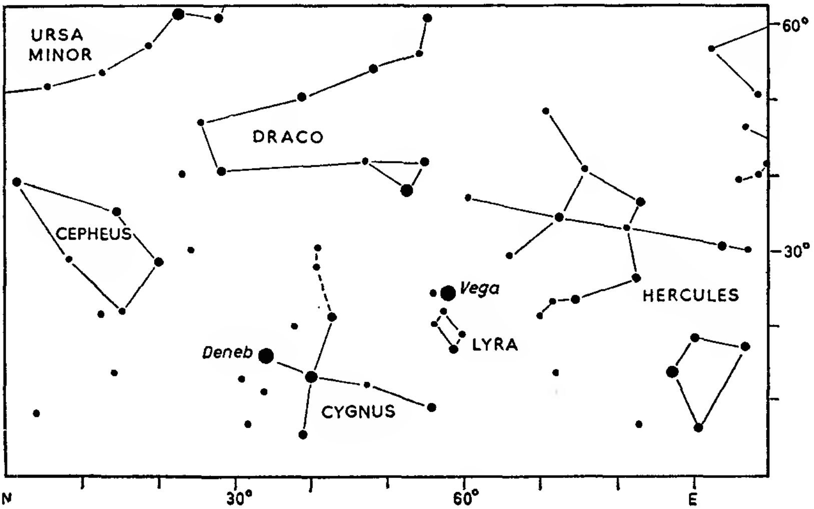
January 6 at 5ʰ	January 21 at 4ʰ
February 6 at 3ʰ	February 21 at 2ʰ
March 6 at 1ʰ	March 21 at midnight
April 6 at 23ʰ	April 21 at 22ʰ
May 6 at 21ʰ	May 21 at 20ʰ





January 6 at 5^{h}	January 21 at 4^{h}	**4R**
February 6 at 3^{h}	February 21 at 2^{h}	
March 6 at 1^{h}	March 21 at midnight	
April 6 at 23^{h}	April 21 at 22^{h}	
May 6 at 21^{h}	May 21 at 20^{h}	





5L

January 6 at	7h	January 21 at	6h
February 6 at	5h	February 21 at	4h
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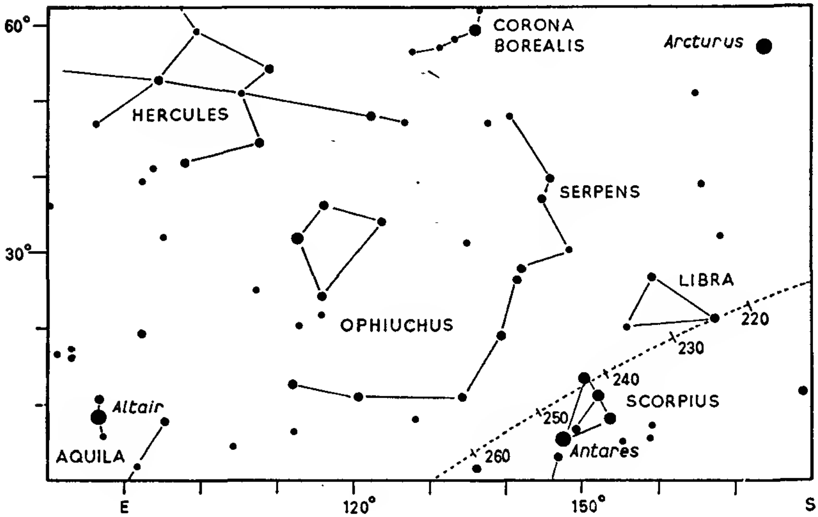
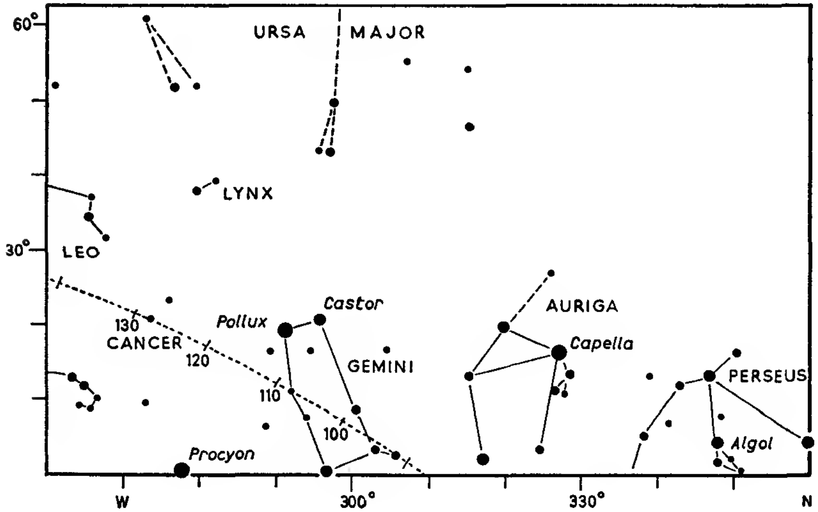
April 6 at	1h	April 21 at	midnight
May 6 at	23h	May 21 at	22h

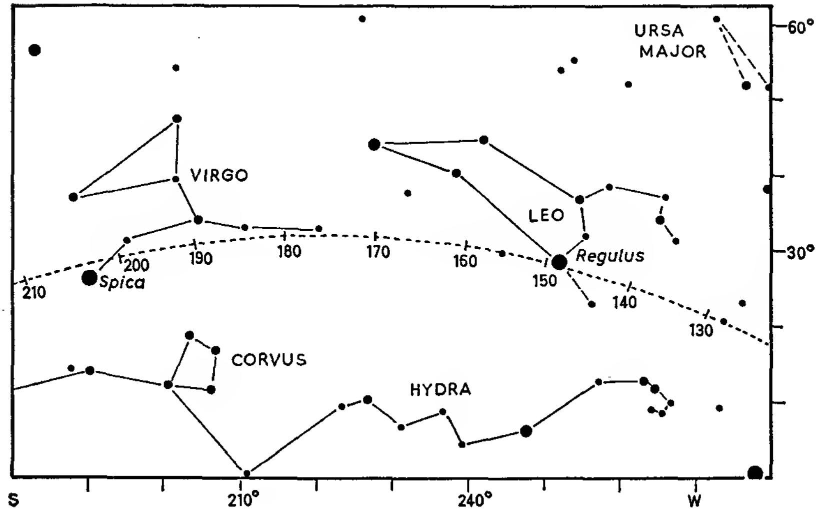


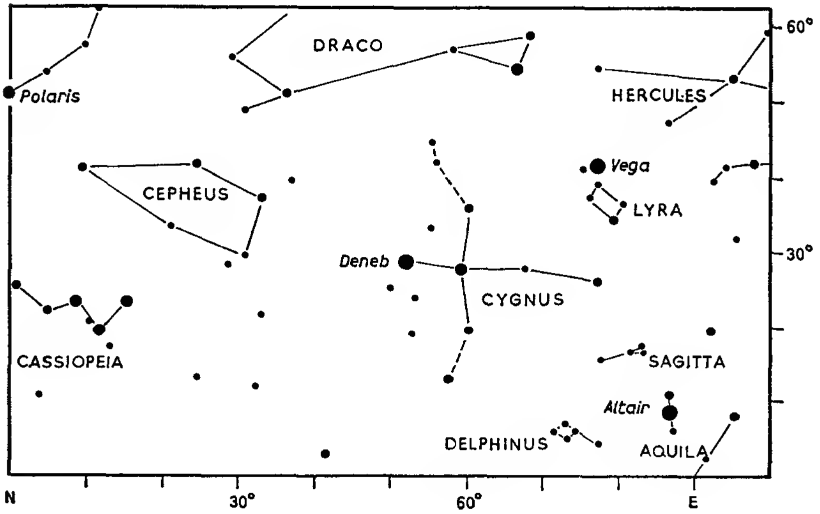


January 6 at 7^{h}
February 6 at 5^{h}
March 6 at 3^{h}
April 6 at 1^{h}
May 6 at 23^{h}

January 21 at 6^{h}
February 21 at 4^{h}
March 21 at 2^{h}
April 21 at midnight
May 21 at 22^{h}

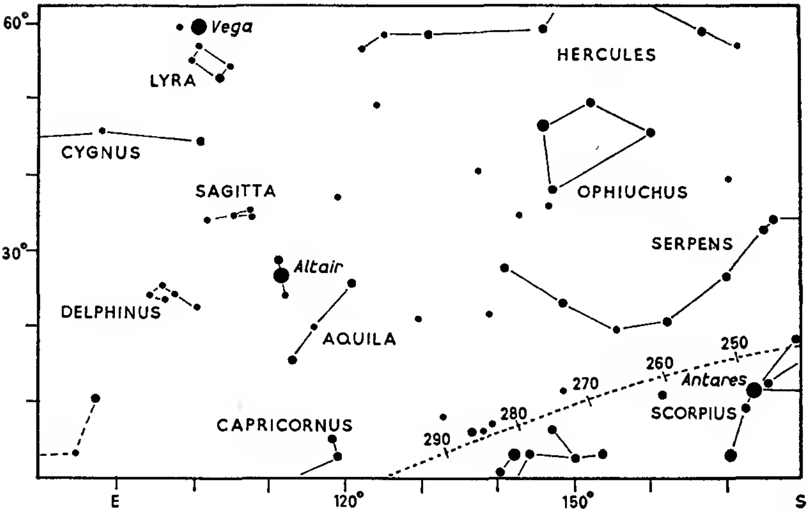
5R

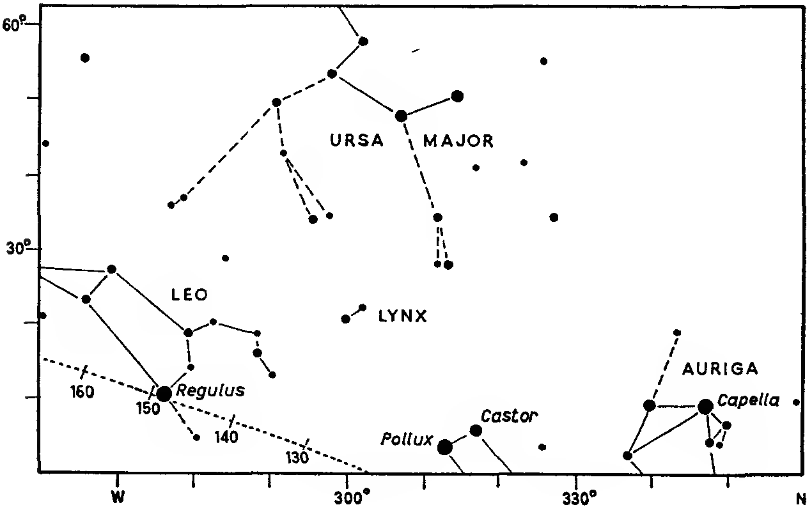




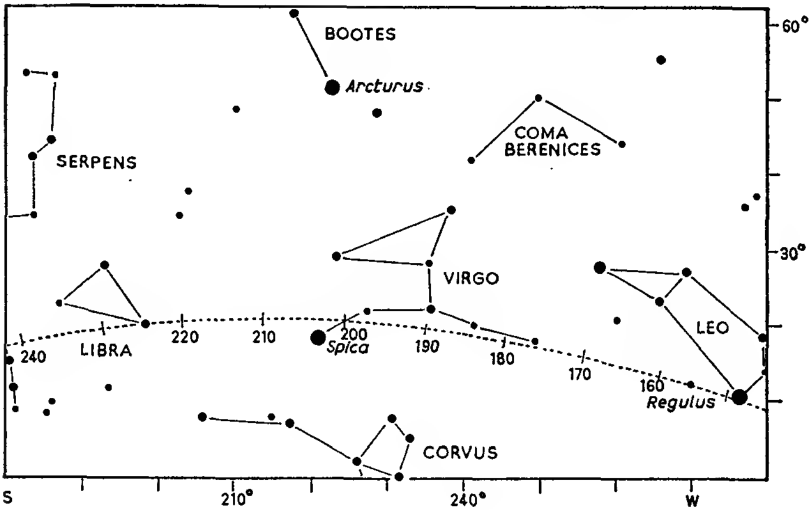
6L

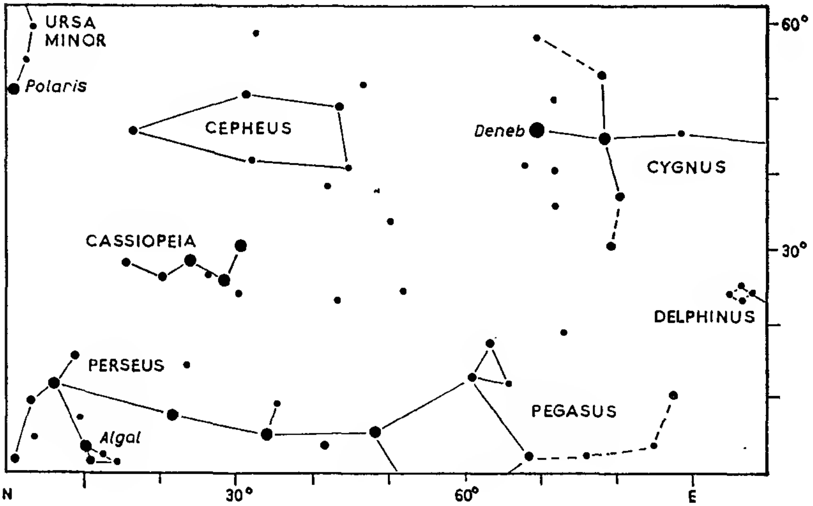
March 6 at 5h	March 21 at 4h
April 6 at 3h	April 21 at 2h
May 6 at 1h	May 21 at midnight
June 6 at 23h	June 21 at 22h
July 6 at 21h	July 21 at 20h





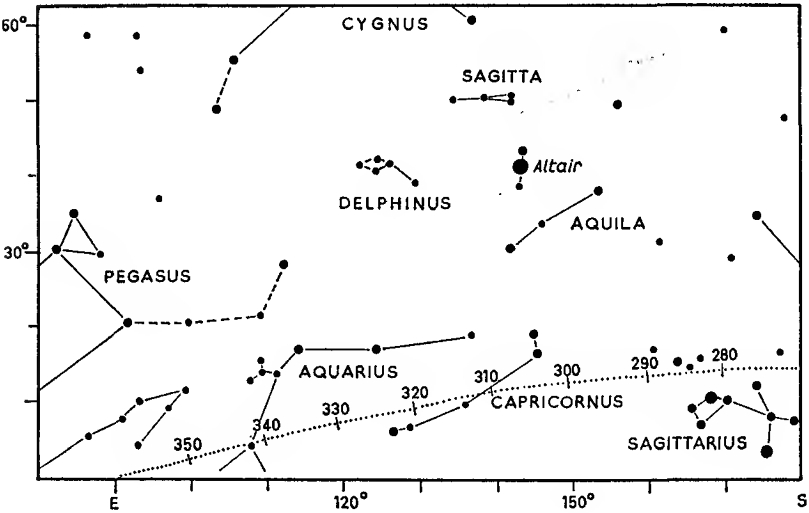
March 6 at 5^h	March 21 at 4^h	**6R**
April 6 at 3^h	April 21 at 2^h	
May 6 at 1^h	May 21 at midnight	
June 6 at 23^h	June 21 at 22^h	
July 6 at 21^h	July 21 at 20^h	

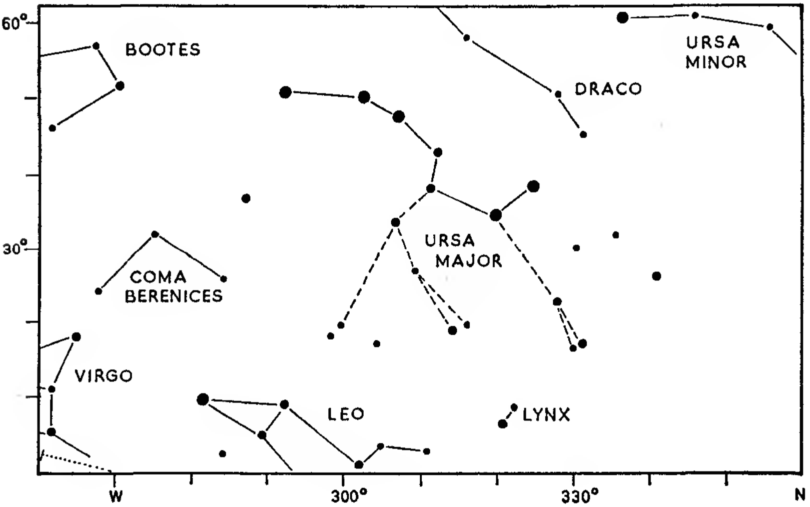




7L

May 6 at 3^h	May 21 at 2^h
June 6 at 1^h	June 21 at midnight
July 6 at 23^h	July 21 at 22^h
August 6 at 21^h	August 21 at 20^h
September 6 at 19^h	September 21 at 18^h

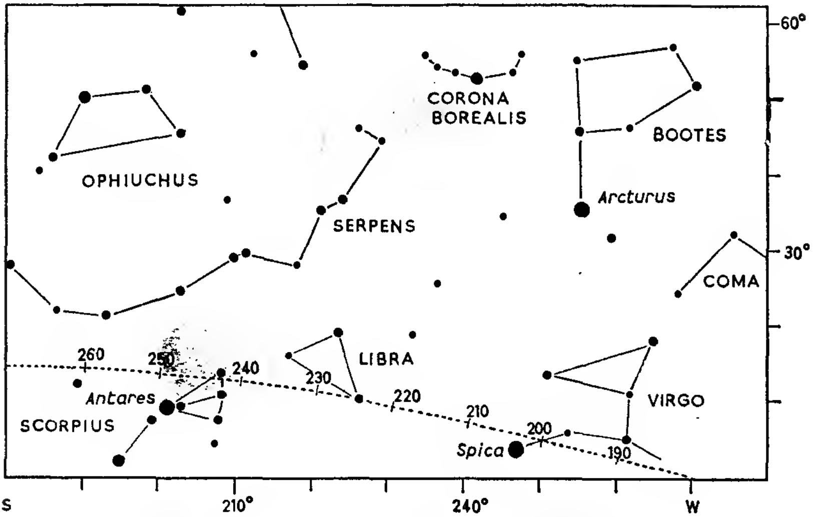


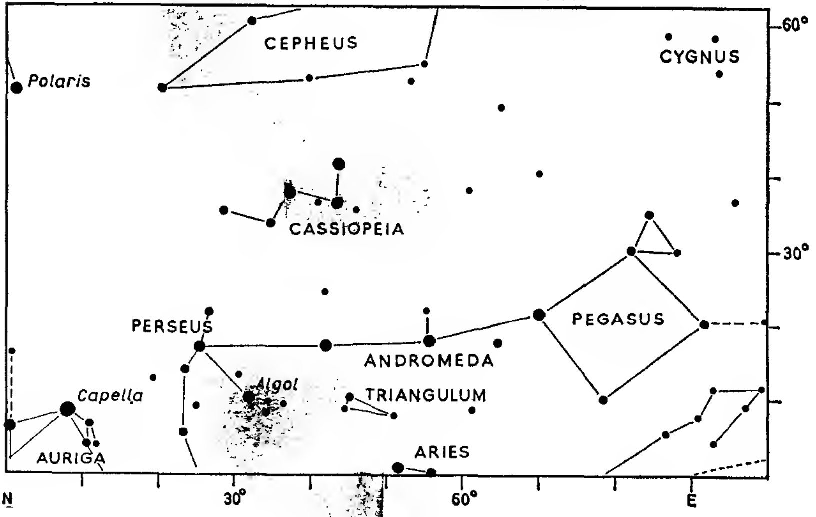


May 6 at 3h
June 6 at 1h
July 6 at 23h
August 6 at 21h
September 6 at 19h

May 21 at 2h
June 21 at midnight
July 21 at 22h
August 21 at 20h
September 21 at 18h

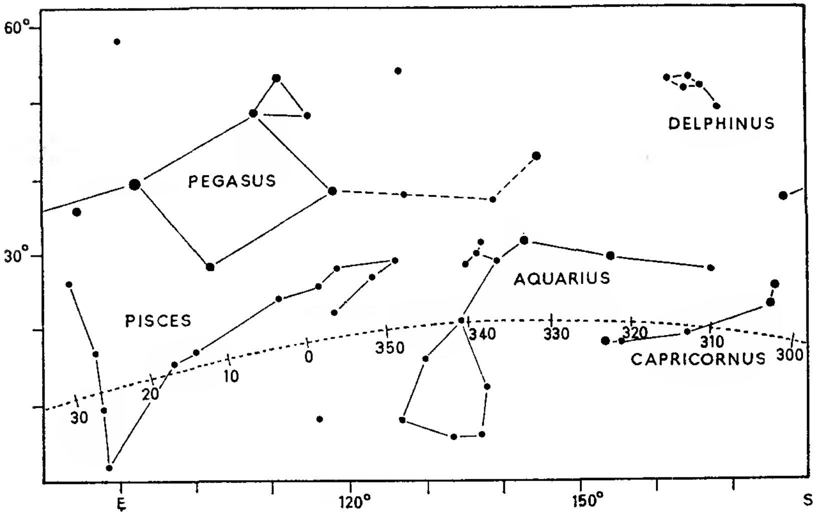
7R

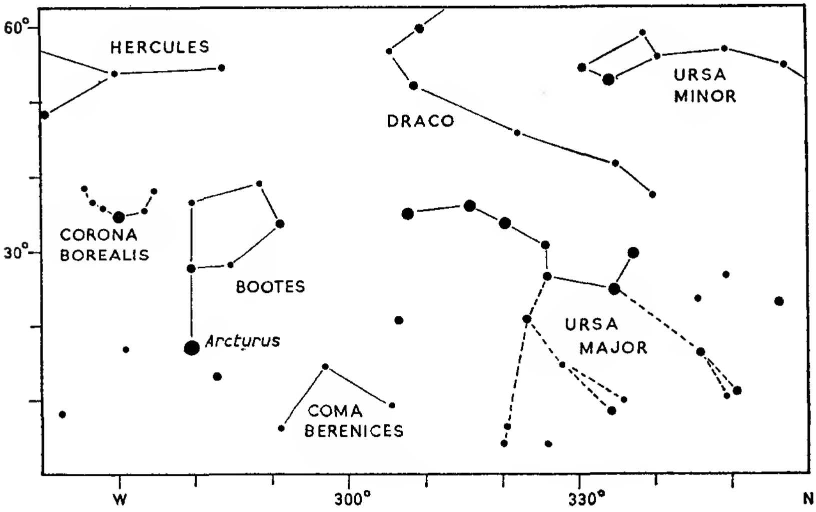




8L

July 6 at 1^{h}	July 21 at midnight
August 6 at 23^{h}	August 21 at 22^{h}
September 6 at 21^{h}	September 21 at 20^{h}
October 6 at 19^{h}	October 21 at 18^{h}
November 6 at 17^{h}	November 21 at 16^{h}





July 6 at 1h	July 21 at midnight
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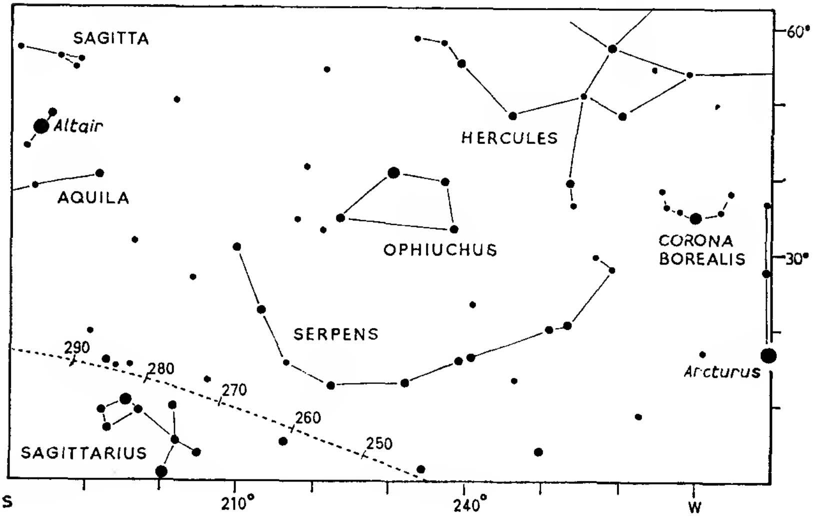
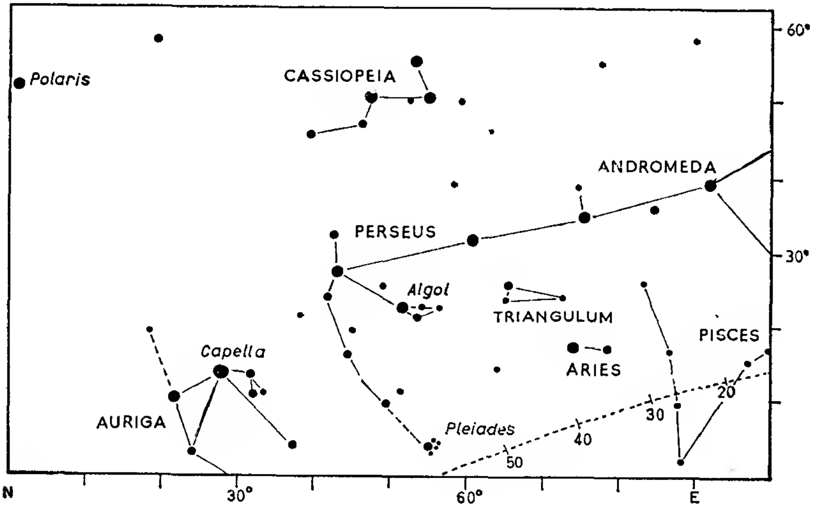
September 6 at 21h	September 21 at 20h
October 6 at 19h	October 21 at 18h
November 6 at 17h	November 21 at 16h

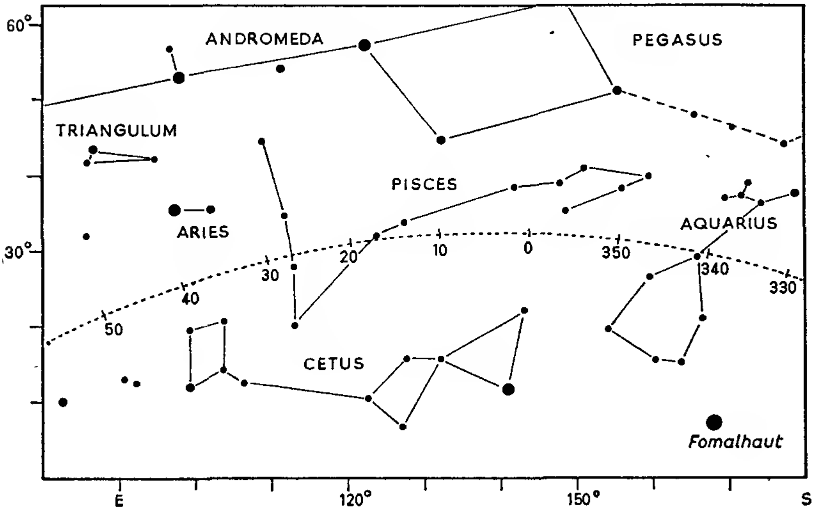
8R

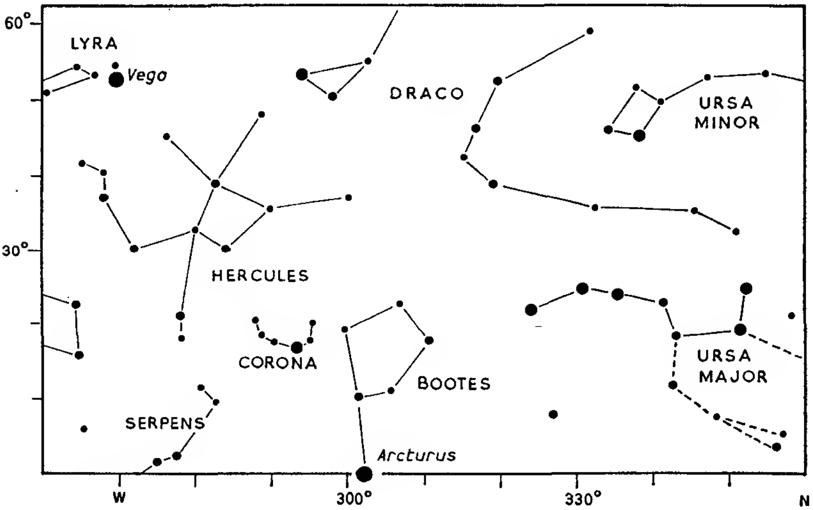




9L

August 6 at 1h	August 21 at midnight
September 6 at 23h	September 21 at 22h
October 6 at 21h	October 21 at 20h
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h





August 6 at 1h	August 21 at midnight
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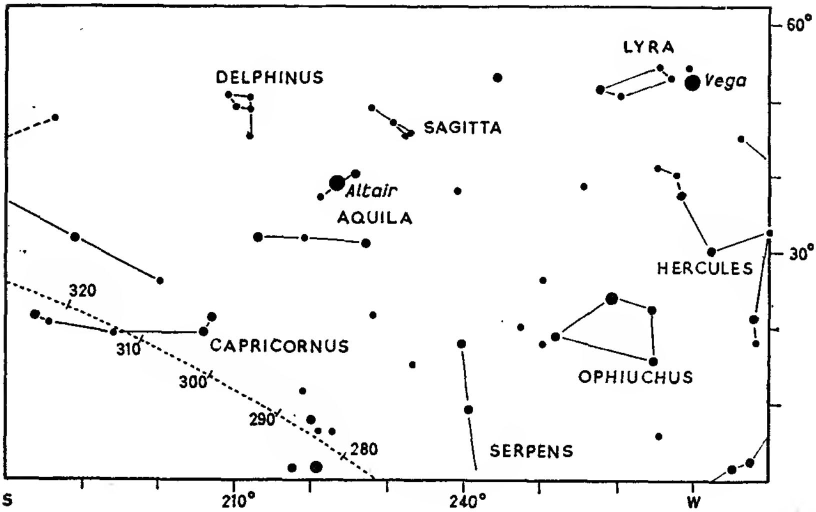
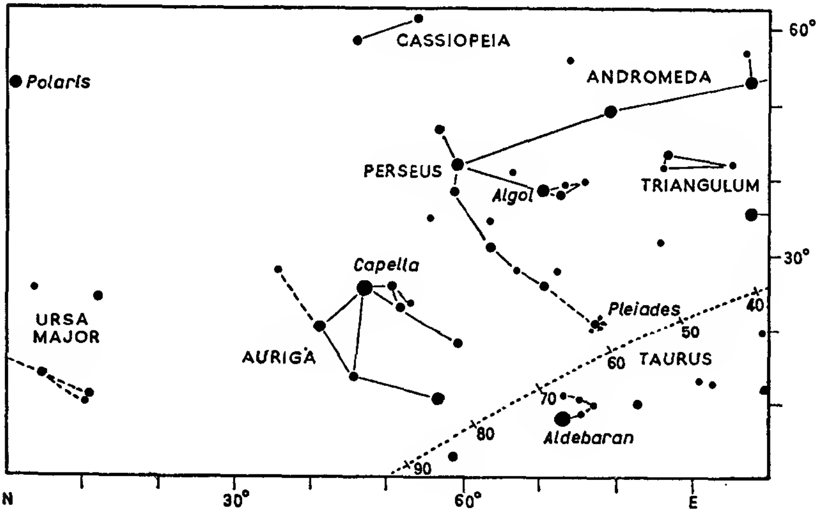
October 6 at 21h	October 21 at 20h
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h

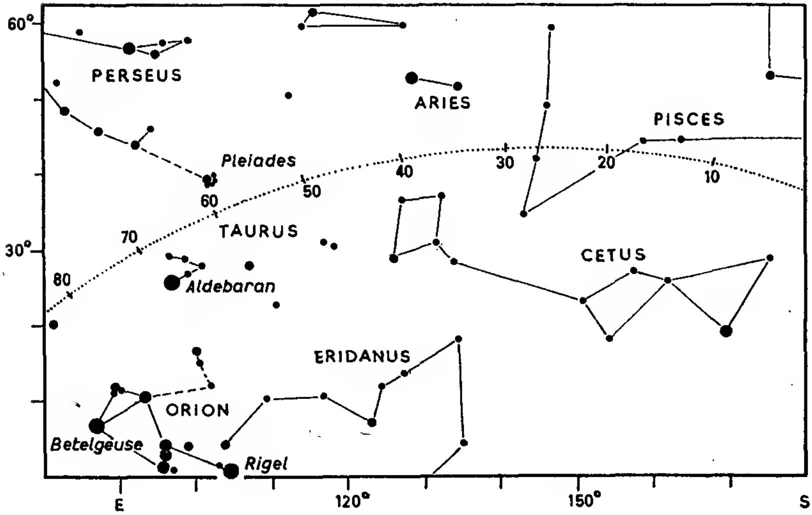
9R

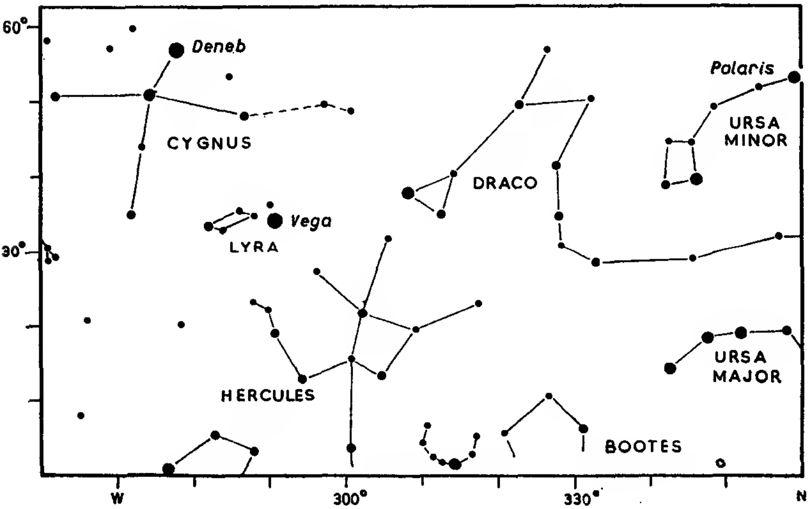




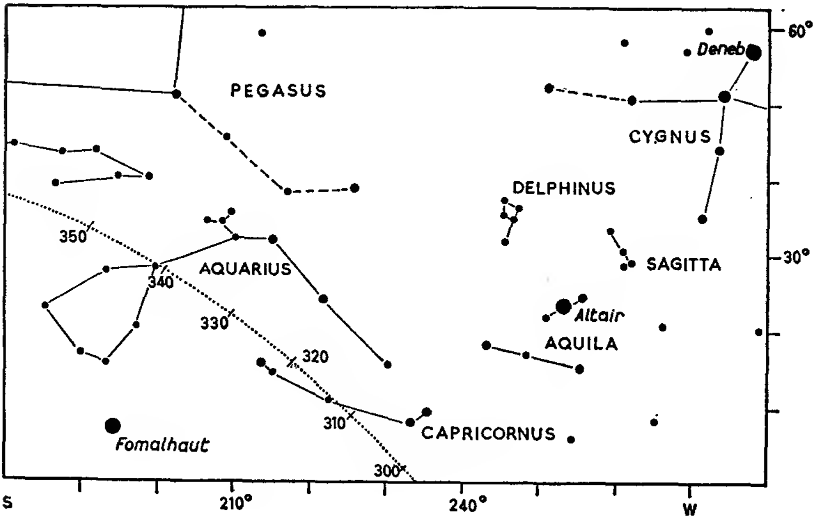
10L

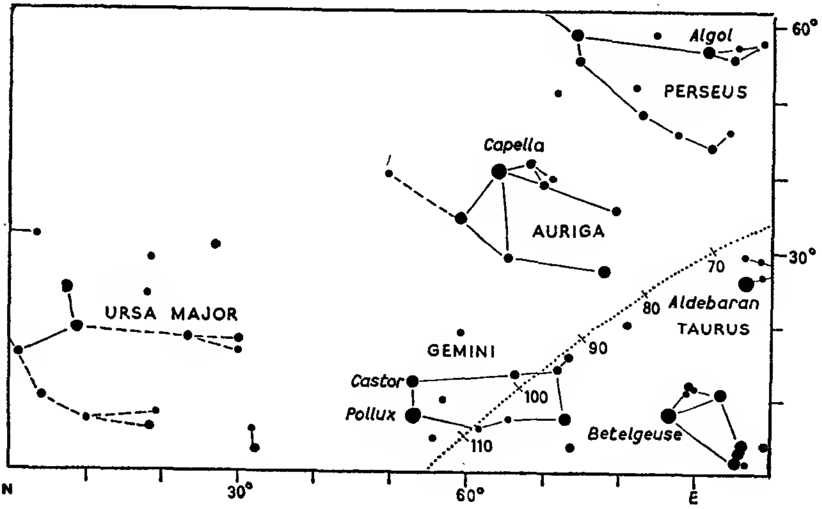
August 6 at 3^h^	August 21 at 2^h^
September 6 at 1^h^	September 21 at midnight
October 6 at 23^h^	October 21 at 22^h^
November 6 at 21^h^	November 21 at 20^h^
December 6 at 19^h^	December 21 at 18^h^





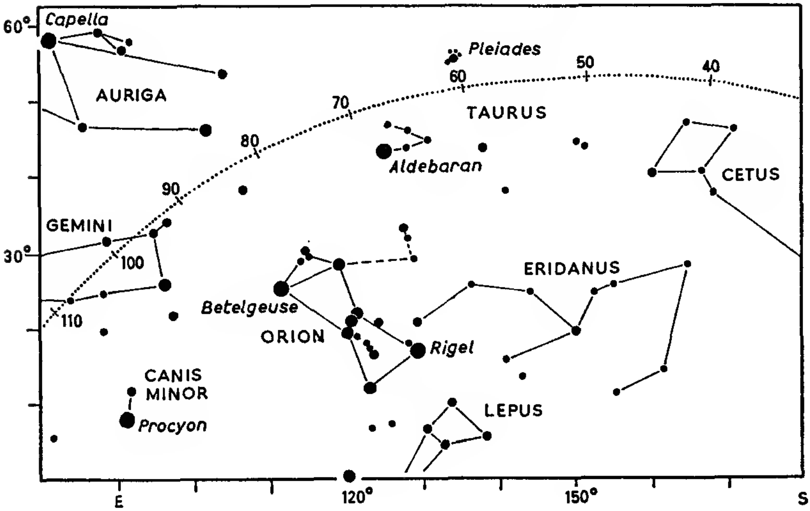
August 6 at 3h	August 21 at 2h		**10R**
September 6 at 1h	September 21 at midnight		
October 6 at 23h	October 21 at 22h		
November 6 at 21h	November 21 at 20h		
December 6 at 19h	December 21 at 18h		

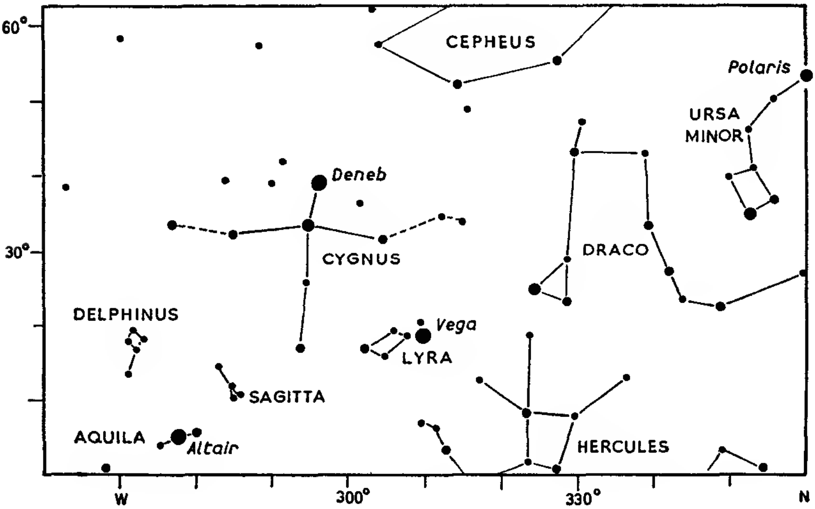




11L

September 6 at 3h	September 21 at 2h
October 6 at 1h	October 21 at midnight
November 6 at 23h	November 21 at 22h
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h

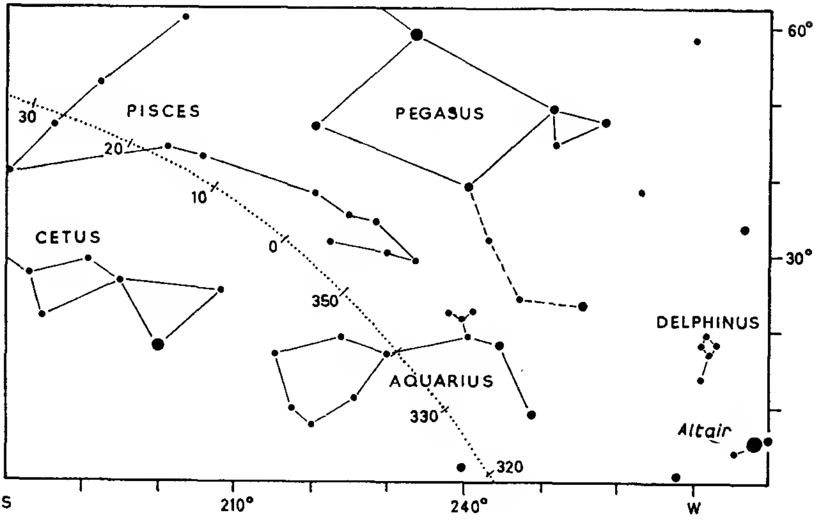


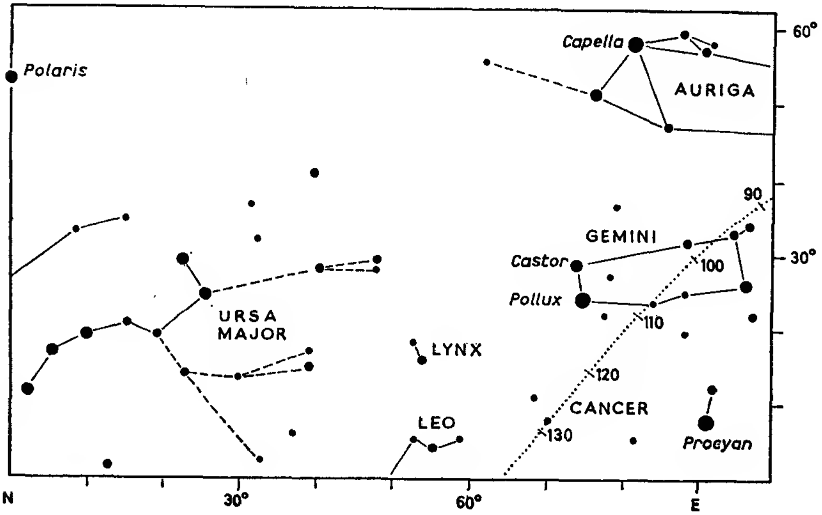


September 6 at 3h
October 6 at 1h
November 6 at 23h
December 6 at 21h
January 6 at 19h

September 21 at 2h
October 21 at midnight
November 21 at 22h
December 21 at 20h
January 21 at 18h

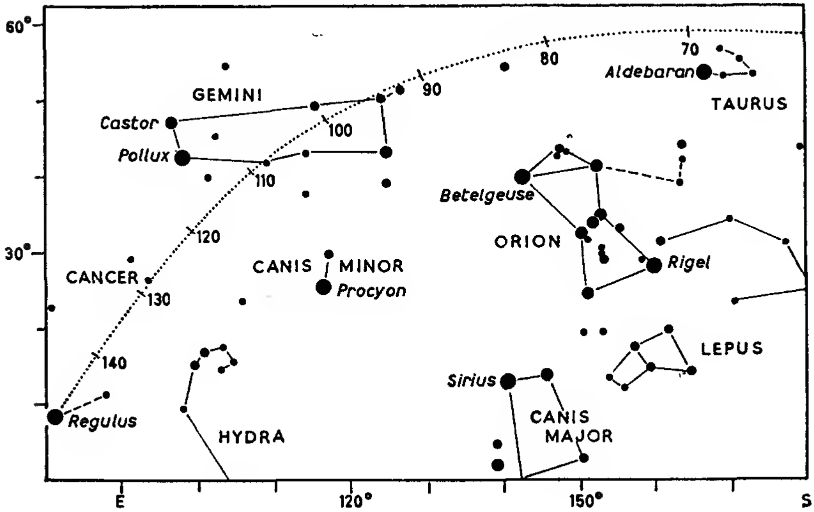
11R

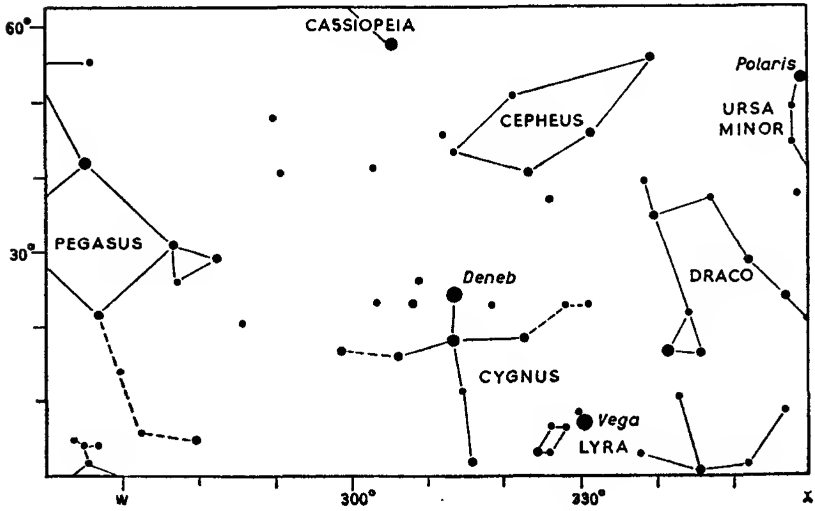




12L

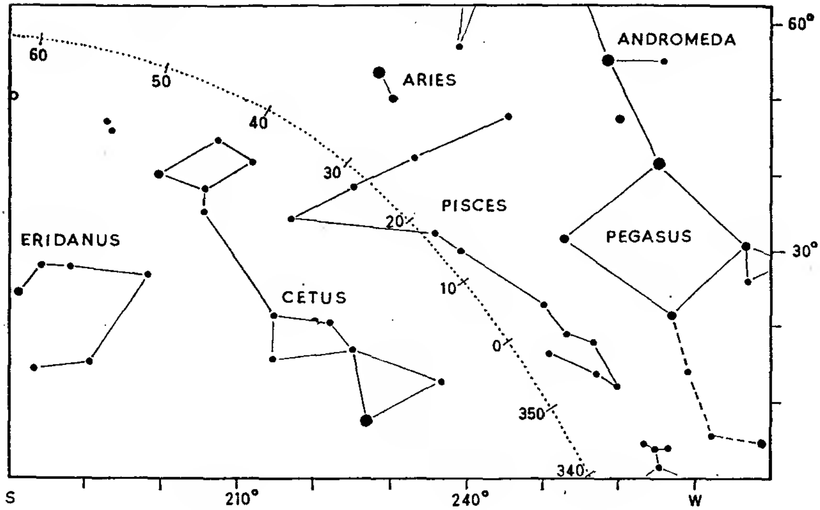
October 6 at 3h	October 21 at 2h
November 6 at 1h	November 21 at midnight
December 6 at 23h	December 21 at 22h
January 6 at 21h	January 21 at 20h
February 6 at 19h	February 21 at 18h

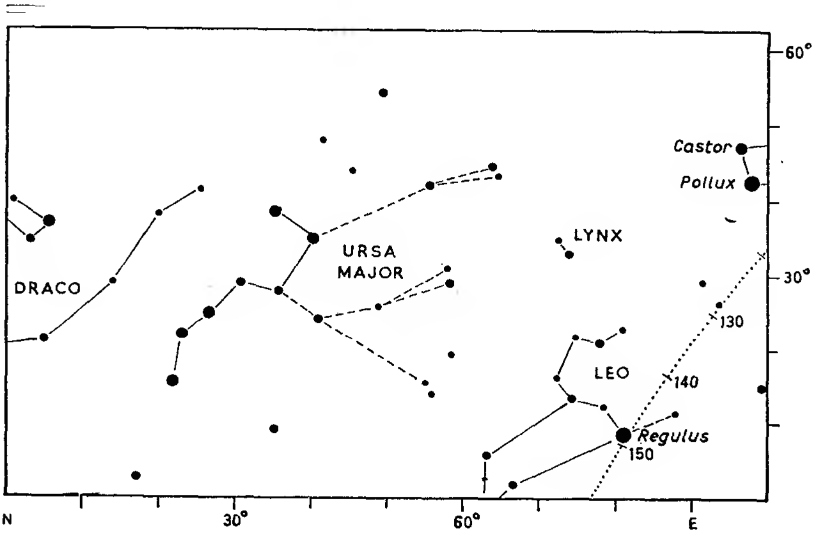


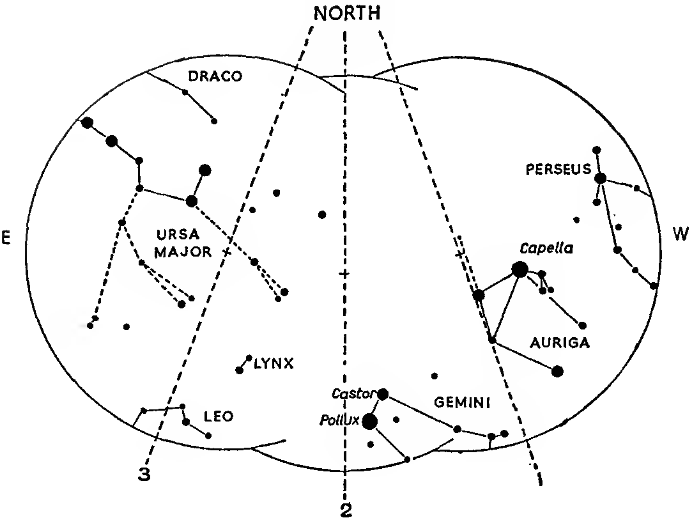


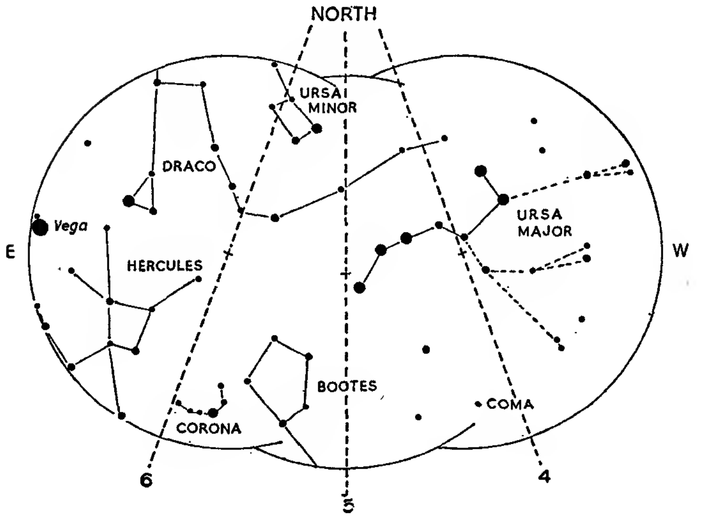
October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h
February 6 at 19^h	February 21 at 18^h

12R

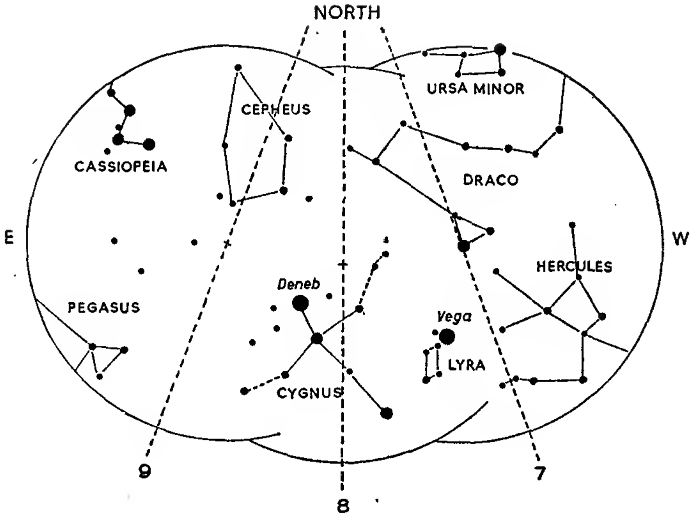


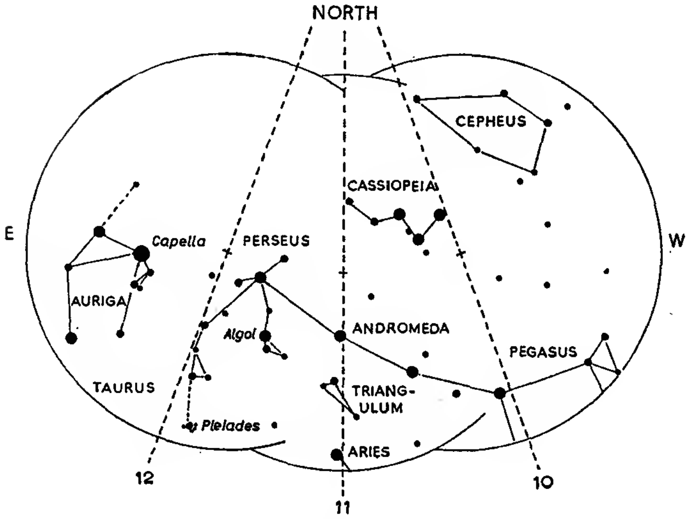






Overhead stars





Overhead stars

The Planets in 1970

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	281°	346°	213°	33°	189°	240°
	21	300	357	215	33	189	241
February	6	320	9	216	34	189	241
	21	339	20	216	35	188	241
March	6	355	29	216	36	188	241
	21	14	40	215	38	187	241
April	6	33	51	214	39	187	241
	21	52	61	212	41	186	241
May	6	70	72	210	43	186	240
	21	88	82	208	45	185	240
June	6	107	92	207	47	185	240
	21	126	102	207	49	185	239
July	6	143	112	207	50	185	239
	21	160	122	208	51	186	239
August	6	177	132	209	52	186	239
	21	193	142	211	53	187	239
September	6	208	152	214	53	188	239
	21	220	162	216	53	189	239
October	6	230	171	219	52	190	239
	21	234	181	223	51	191	240
November	6	229	191	226	50	192	240
	21	221	200	229	49	192	241
December	6	221	210	233	48	193	241
	21	228	219	236	47	194	242
Conjunction:							
Inferior		Nov. 10	—	—	—	—	—
Superior		Jan. 24	Aug. 2	Nov. 9	May 2	Oct. 2	Nov. 23
Opposition:		—	—	Apr. 21	Nov. 11	Mar. 27	May 21

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *What is the bright planet seen in the east some degrees to the right of the Pleiades on October* 20 *at* 20^h*?*

The lower chart 9R shows this part of the sky on the given date, and it gives the approximate longitude of the planet as 50°. The table opposite shows that Saturn is the only planet near this position.

(2) *Where may Mars be found on January* 4*?*

The table opposite shows that the longitude of Mars on this date is about 346°, and from the star charts this position is only visible in January on charts 11R and 12R. It is then seen that Mars will be setting in the south-west, just after 21^h.

The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about 23½ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the following pages.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals between them are not equal. Thus if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

		Mercury	*Venus*
Inferior conj.	to Elongation West	22 days	72 days
Elongation West	to Superior conj.	36 days	220 days
Superior conj.	to Elongation East	36 days	220 days
Elongation East	to Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, itis alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most noticeable with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in

Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1971), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. The rings are now opening, and the planet is growing brighter at each opposition.

Uranus, *Neptune* and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the March and May notes.

Phases of the moon, 1970

New Moon				*First Quarter*				*Full Moon*				*Last Quarter*			
	d	h	m		d	h	m		d	h	m		d	h	m
Jan.	7	20	36	Jan.	14	13	18	Jan.	22	12	55	Jan.	30	14	39
Feb.	6	07	13	Feb.	13	04	10	Feb.	21	08	19	Mar.	1	02	33
Mar.	7	17	43	Mar.	14	21	16	Mar.	23	01	53	Mar.	30	11	05
Apr.	6	04	09	Apr.	13	15	44	Apr.	21	16	21	Apr.	28	17	18
May	5	14	51	May	13	10	26	May	21	03	38	May	27	22	32
June	4	02	21	June	12	04	07	June	19	12	28	June	26	04	01
July	3	15	18	July	11	19	43	July	18	19	59	July	25	11	00
Aug.	2	05	58	Aug.	10	08	50	Aug.	17	03	15	Aug.	23	20	34
Aug.	31	22	01	Sept.	8	19	38	Sept.	15	11	10	Sept.	22	09	42
Sept.	30	14	32	Oct.	8	04	43	Oct.	14	20	21	Oct.	22	02	47
Oct.	30	06	28	Nov.	6	12	47	Nov.	13	07	28	Nov.	20	23	13
Nov.	28	21	14	Dec.	5	20	36	Dec.	12	21	03	Dec.	20	21	09
Dec.	28	10	43												

All times are G.M.T.

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MONTHLY NOTES, 1970

January

New Moon: January 7 *Full Moon:* January 22

Earth is at perihelion (nearest to the Sun) on January 1, at a distance of 91,400,000 miles (147,100,000 km).

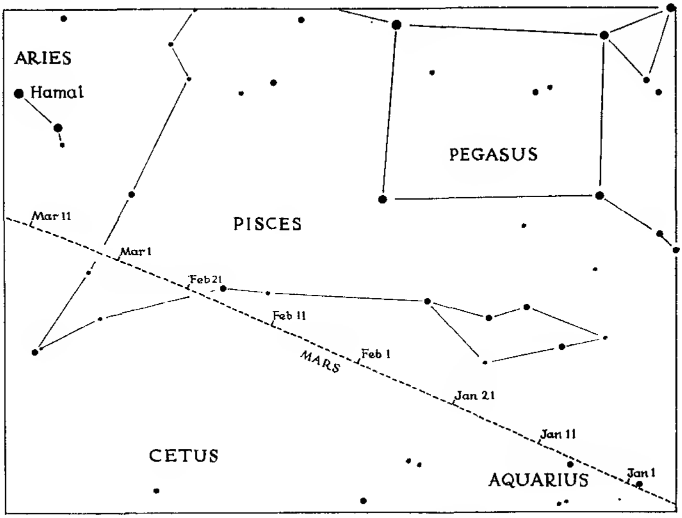
Mercury is in inferior conjunction on January 13 and will not be visible until the end of the month, when it begins to appear as a morning star.

Venus is in superior conjunction on January 24 and will not be seen. After conjunction the planet appears as an evening star for the next eight months, but this is not a very favourable apparition, since greatest eastern elongation occurs in September, when the ecliptic is low in the evening sky.

Mars is an evening star, setting about two hours before midnight. The planet is moving direct in Aquarius, and passes into Pisces in the middle of the month. This movement carries the planet rapidly to the north, and as a result, the time of setting remains about the same for several months. There is no opposition of Mars in 1970, and as its distance from the Earth increases, it grows steadily fainter (magnitude +1·0 to +1·3).

Jupiter was in conjunction last October, and is now a morning star, rising south of east an hour or two after midnight. It will be seen near the eastern border of Virgo (see diagram on page 60) and during the month it moves slowly to the east. It is now drawing nearer to the Earth and growing brighter (magnitude −1·5 to −1·7).

Saturn was in opposition last October, and is now an evening star, setting in the west at about 2^h. The planet is at a stationary point on January 4 at the junction of the constellations Pisces, Aries and Cetus. Its magnitude is about +0·5, and it should easily be recognized, since it is the brightest star in this region. The apparent path of Saturn during the year is shown in the diagram on page 74.



Mars, January to March 1970

The Crab Nebula. Of all the objects in the stellar sky, one of the most interesting and important is the Crab Nebula, which is now excellently placed for observation in the evening sky. It is not visible with the naked eye, but a 3-inch telescope will show it as a faint misty patch, and it has been known for more than 200 years. Apparently it was discovered by John Bevis in 1731; in 1758 Charles Messier rediscovered it independently, and made it the first entry in his famous catalogue of clusters and nebulæ. Therefore the Crab is known officially as M1, or as N.G.C. 1952 (the 1,952nd object in Dreyer's New General Catalogue). Its integrated magnitude is 8·4, and its position R.A. 5^{h} $31{\cdot}5^{m}$, decl. +21°59′. It lies not far from the third-magnitude star Zeta Tauri.

The Crab looks unspectacular enough when seen visually in small telescopes, but photographs taken with large instruments show considerable structure – and the Crab is no ordinary nebula. It is the remnant of a supernova which was observed by Chinese and Japanese astronomers in the year 1054, and which became so bright that for several months it was visible in broad daylight. Yet the actual outburst occurred not in 1054, but in the time of Ancient Egypt, since the Crab is about 4,000 light-years away from us, and so our information about it is 4,000 years out of date.

The nebula is still expanding outward from the old explosion centre, and the gases in it are violently agitated. They emit not only visible light, but also radio waves; in fact the Crab is one of the strongest radio sources in the entire sky, and was one of the first sources to be identified with an optical object. Moreover, its position in the Zodiac means that every summer it lies almost behind the Sun in the sky, and is hidden or occulted by the 'radio Sun', which is considerably larger than the Sun we see visually. As the Crab passes behind the solar corona, its radio emissions are cut off, and the extent and duration of the cut-off is a key to the size of the Sun's radio surround.

As well as emitting visible light and radio waves, the Crab is a source of X-radiation, and also of gamma-radiation. If this were not enough, it has now been found to contain two pulsars. Pulsars, those strange, rapidly vibrating radio sources detected by Cambridge workers in 1967–8, are still very much of a mystery, but they may well be neutron stars. In early 1969 one of the Crab pulsars was detected optically, which adds force to the neutron-star theory. What is particularly valuable is that in this case we know the distance of the pulsar; it must be the same as that of the Crab Nebula itself – that is to say, 4,000 light-years.

Only four supernovæ have been seen in our Galaxy in historical times, and of these only the star of 1054 has left obvious traces visible in small telescopes. Certainly, studies of the Crab Nebula have led to great advances in our overall knowledge; to astrophysicists and radio astronomers, this curious gas-cloud is one of the most important and significant objects in the whole sky.

The Earth at Perihelion. On January 1 the Earth reaches its closest point to the Sun. Some people still find it hard to believe that we are at our closest-in when Europe and North America are experiencing winter, with its snows and low temperatures; but in fact the Earth's orbit is so nearly circular (eccentricity a mere 0·017) that the changing distance makes very little difference to the seasons. The seasons are, of course, due to the fact that the Earth's axis is tipped by $23\frac{1}{2}$° to the perpendicular.

Argo Navis. Argo Navis, the Ship Argo – named in honour of the mythical craft which carried Jason and his companions in their quest of the Golden Fleece – was the largest of the classical constellations. It was, however, too large to be convenient, and it has now been chopped up into various sections, of which the most important are Carina (the Keel), Vela (the Sails), and Puppis (the Poop). Of these Carina is the brightest, and contains Canopus, the brilliant yellow giant which outshines all stars apart from Sirius; but it, together with Vela, is too far south to be seen from the latitudes of Europe or New York State. However, a few stars of Puppis may be seen low over the southern horizon, south and east of Sirius, and January evenings are the best times to look for them.

February

New Moon: February 6 *Full Moon:* February 21

Mercury is at greatest western elongation as a morning star on February 5; it may then be possible to see the planet a few degrees above the horizon in the south-east before sunrise.

Venus is now an evening star, but it is only a few degrees from the Sun and sets shortly after sunset.

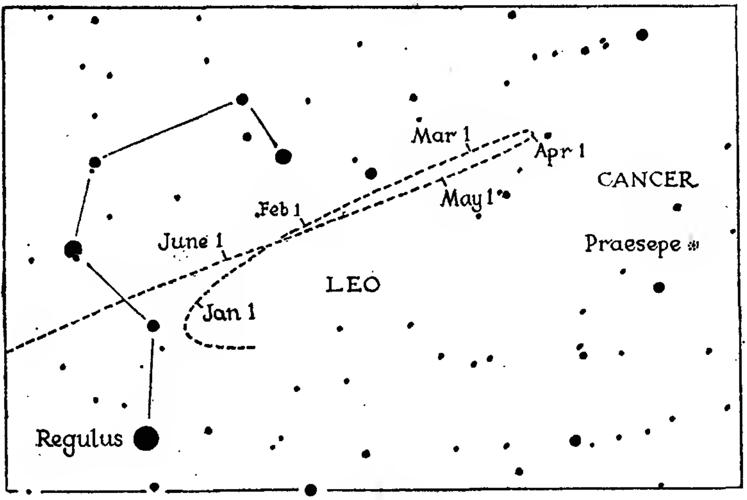
Mars continues to grow fainter as its distance increases (magnitude +1·3 to +1·5). It is an evening star, setting at about 2^h, and may be seen below the Great Square of Pegasus, moving quite rapidly through the faint stars of Pisces. This rapid direct motion continues throughout the year, so that it travels two-thirds of the way round the sky by the end of December.

Jupiter rises at midnight in mid-February and may be seen in Virgo near the border with Libra. The planet reaches a stationary point on February 20, and then begins to move back again to the west, towards Spica. The brilliance of Jupiter (magnitude −1·7 to −1·9) in this rather bare region of the sky is quite striking.

Saturn is an evening star (magnitude +0·6) moving direct in Aries and setting in the west about midnight at the beginning of the month.

Vesta, the brightest of the minor planets, is at opposition on February 8, and since it reaches magnitude 6·3, it should be possible to see it with binoculars. The diagram shows its position near the Sickle of Leo, and includes all stars down to magnitude 6·5. The planet will be most readily identified by its rapid motion, amounting to more than a quarter of a degree per day towards the west.

A partial eclipse of the Moon will occur on February 21, but it is of small magnitude, and although visible in North America, will not be seen in the British Isles (see notes on page 96).



Vesta, 1970

An occultation of Regulus may be observed in the early morning hours of February 21. The Moon moves to the east in front of the star, and Regulus will disappear on the left side of the Moon's disk at about $2^h\ 10^m$, reappearing at the right hand limb at about $3^h\ 23^m$. The times vary a little in different parts of the country, but in any case timing will be difficult since the glare of the Full Moon tends to hide the light of the star.

28 days in February. 1970 is not a Leap Year. Divide by 4, and there will be a remainder – so that February has only its customary 28 days. The next Leap Year will be 1972.

Vesta. Between the orbits of Mars and Jupiter move the great majority of the asteroids or Minor Planets—small worlds which may well be the débris of an old planet (or planets) which met with disaster in the remote past. Few of them exceed 100 miles in diameter, and only a handful have diameters of as much as 200 miles. One of the largest is Vesta, which has also the distinction of being the only asteroid ever visible with the naked eye. It is 241 miles across; it is surpassed only by Pallas (304 miles) and Ceres (430 miles), both of which are farther away, less reflective, and therefore fainter as seen in our skies.

Vesta was discovered in 1807, and was the fourth asteroid to be found; not until 1845 did the fifth, Astræa, come to light. It is easy to see with binoculars, but it looks exactly like a star, and to recognize it the observer must know his star-field. This year it is in Leo, so that it is well north of the celestial equator, and should be identified without much difficulty.

Because Vesta is so small compared with a true planet, it can retain no vestige of atmosphere. Its escape velocity is very low, but it would be wrong to suggest (as some science-fiction writers have done) that an astronaut standing on its surface could jump clear simply by the power of his leg muscles. This would be possible only with an asteroid of less than 2 miles in diameter, assuming a density comparable with that of the Earth.

Vesta is moving in a stable orbit; its mean distance from the Sun is 219,300,000 miles, so that it never comes within 100,000,000 miles of the Earth, and there is not the slighest danger of a collision. This also applies to the other large asteroids. There are some smaller members of the swarm whose eccentric orbits carry them much closer to the Sun; indeed, Hermes – a small body only a mile across – brushed past us in 1937 at a mere 485,000 miles, less than twice the distance of the Moon. Fortunately, the danger of our being hit by any asteroid is so slight that it can be neglected.

AD Leonis. The second-magnitude star Gamma Leonis, in the Sickle, is a well-known binary. In the same field with it is a much fainter star, AD Leonis, which is quite unconnected with Gamma; it is far closer to us, and is a dim Red Dwarf. What makes it so interesting is that it is a 'flare star'. Its normal magnitude is 9·4, but it may brighten up sharply over a period of only a minute or so, fading back to its usual brilliance more slowly.

Various flare stars are known. All are Red Dwarfs, and it is thought that their behaviour must be due to phenomena similar to flare activity on the Sun – but relatively speaking, upon a much grander scale. Observations of them are far from complete, and AD Leonis is a suitable star to be watched, if only because its position close to Gamma makes it so easy to identify. Detailed charts were given in recent issues of *Planetarium* Magazine.

Lunar Occultations. The occultation of Regulus this month will be well worth watching, if only because the disappearance and reappearance will be so abrupt. The Moon has no appreciable atmosphere around its limb, so that a star seems to shine steadily until it is actually cut off; when it vanishes, the disappearance is to all intents and purposes instantaneous. This is not the case when the planet Venus occults a star, because Venus has a dense atmosphere, and the star flickers and fades briefly before disappearing.

Lunar occultations show clearly that the Moon's atmosphere is of negligible density. Nowadays, much more refined methods have proved that the Moon has lost almost the whole of any atmosphere it may once have had.

March

New Moon: March 7 *Full Moon:* March 23

Equinox: March 21

Mercury is in superior conjunction on March 23 and will remain invisible throughout the month.

Venus is now slowly moving out to the east of the Sun at the end of March it sets more than an hour after sunset. It may then be seen low in the west, a bright object (magnitude −3·4) in the twilight sky.

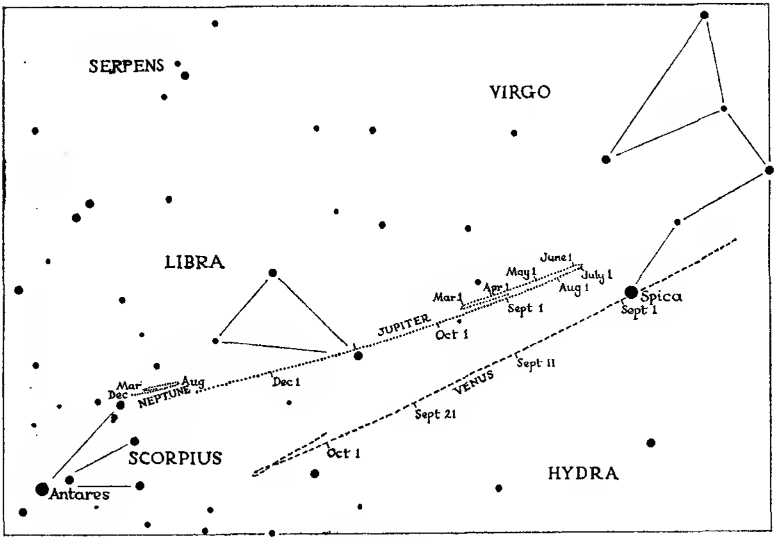
Mars is still an evening star, setting about the same time in the early morning hours. The planet moves from Pisces into Aries in the early part of March, towards the planet Saturn, and passes 3 degrees north of that planet on March 17. Saturn will then be a whole magnitude brighter than Mars (Saturn +0·6, Mars +1·6).

Jupiter is a brilliant object, moving retrograde in the eastern part of Virgo. It rises an hour before midnight at the beginning of March, and grows even brighter (magnitude −1·9 to −2·0) as it approaches opposition.

Saturn may be seen in the early evening in the western sky, a few degrees below the Pleiades, and setting two to three hours before midnight. The conjunction with Mars on March 17 is referred to above, and may be inferred from the diagram on page 74.

Uranus is at opposition on March 27, and its position at that time is shown on the diagram on page 88. Its distance at opposition is about 1,610 million miles (2,590 million km) and it will then be just visible to the naked eye (magnitude +5·7); in a small telescope it appears as a greenish disk.

Pluto is also at opposition, on March 17, and its position is shown on the same diagram. The planet is too faint to be seen with small instruments (magnitude about +14). The distance at opposition is about 2,850 million miles (4,590 million km).



Jupiter, 1970

A total eclipse of the Sun takes place on March 7, but is visible only in the Americas (see notes on page 96).

A Trans-Plutonian Planet? At its opposition this month, Pluto is still a faint object. Its magnitude is around +14, but the exact value is by no means certain, and amateurs with adequate instruments and charts can do useful work in checking it.

Pluto was discovered in 1930. Its rather eccentric orbit swings it within the orbit of Neptune (though because of the high inclination, 17 degrees, there is no chance that the two planets will collide). It will come to perihelion in 1989, and will then be rather brighter than it is now. Yet Pluto will always remain obscure, and there is some doubt as to its nature. On one theory, it used to be a satellite of Neptune, but broke away, and moved off along an independent orbit. If this is true, it is not a genuine planet – and we may well ask whether there is another outer planet awaiting discovery.

In fact Pluto has provided astronomers with puzzle after puzzle. Slight irregularities in the movements of the outer giants, Uranus and Neptune, led the famous American astronomer Percival Lowell to work out the position of a hypothetical trans-Neptunian planet; and fourteen years after Lowell's death in 1916 the planet was duly found, at the observatory which Lowell had founded. But, oddly enough, it was much smaller than had been expected. Pluto is not a giant; recent measures indicate that it is considerably smaller than the Earth. If it is of normal density, it could not therefore perturb Uranus or Neptune appreciably; and yet it was by these very perturbations that Lowell had worked out where Pluto must be.

The situation has always been unsatisfactory, and various ideas have been put forward. It has been suggested, for instance, that Pluto is of extremely high density and mass; alternatively, it has been proposed that it is larger than the measures indicate, and that specular reflection effects are involved. On the other hand, there is always the chance that Lowell's calculations related not to Pluto, but to another planet still farther from the Sun.

Tracking down a trans-Plutonian planet is bound to be a very difficult matter, particularly as we do not know definitely whether it exists, and we have no reliable idea of where it might be. It is bound to be faint, and this means using a giant telescope upon a systematic hunt. Unfortunately, all the world's giant telescopes are busy upon astrophysical programmes, and cannot be spared to go upon a planet-hunt which might easily prove to be abortive in the end.

There the matter rests at present. The trans-Plutonian planet may exist, but its discovery is likely to be something of a matter of luck. We can only hope that it will come to light eventually.

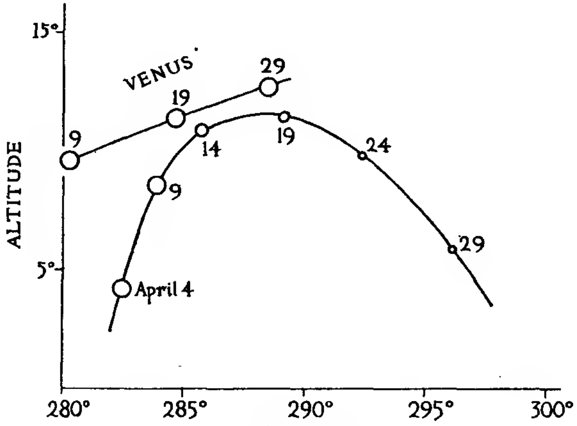
This Month's Total Eclipse. The March 7 total solar eclipse will be well observed, because the track crosses suitable areas (Florida, for instance) and the duration of totality is almost 3½ minutes – much longer than that of the Siberian eclipse of 1968, which lasted for only 42 seconds. Expeditions from many countries will be situated along the track of totality, particularly as there is every chance that the weather will be good. Solar maximum is well past, and so the corona is likely to be of what we may call 'intermediate' type.

A Planetary Conjunction. Amateur photographers may well want to take advantage of the conjunction on March 17, when Saturn and Mars will be only 3 degrees apart. Beginners in astronomy might be excused for supposing that the two planets are really close together – but, of course, nothing could be farther from the truth. We are dealing with nothing more than a line of sight effect, since Saturn is a great deal farther away from Mars than we are. At the moment Mars is far from spectacular; there is no opposition in 1970, but next year the planet will be a glorious object, and at its best will outshine every other celestial body apart from the Sun, the Moon, and Venus. Even when badly placed, as it is this March, it is still recognizable because of its strong red hue which led the ancients to name it in honour of the mythological God of War.

April

New Moon: April 6 *Full Moon:* April 21

Mercury is at greatest eastern elongation on April 18 (20 degrees) and this will be a favourable opportunity to see this planet as an evening star. The diagram shows the changes in altitude and azimuth (true bearing from the north through east, south, and west) of Mercury on successive evenings when the Sun is 6 degrees below the horizon; this will be about 35 minutes after sunset at this time of year. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest before the date of elongation. The diagram also shows the positions of Venus at this time; there is no likelihood of confusion, since Venus is so much brighter than Mercury and farther to the south. Saturn is also in the neighbourhood, but much fainter and is not likely to be seen in the strong twilight.



Mercury, 1970

Venus is a brilliant evening star (magnitude −3·4), setting north of west about two hours after the Sun in mid-April. The planet passes 2 degrees north of Saturn on April 11, but Saturn will be difficult to see in the bright twilight sky.

Mars is still an evening star, still setting about 22^h, but now decidedly fainter than it was at the beginning of the year (magnitude +1·7 to +1·8). During the month it passes from Aries into Taurus and may be seen a few degrees south of the Pleiades in mid-April.

Jupiter comes to opposition on April 21, and then rises south of east at sunset, and is visible all night. It is a brilliant object of magnitude −2·0 in Virgo, its distance at opposition being about 412 million miles (664 million km); but it is now 12 degrees south of the equator, so that even in southern England, it does not rise more than 28 degrees above the southern horizon at midnight. The eclipses and transits of the four great satellites of Jupiter are always worth studying with a small telescope, but the planet is now tilted about 3 degrees (with the north pole away from the Earth) and this is sufficient to cause the fourth satellite to pass north or south of the planet at each conjunction. As a result, there are no eclipses or transits of Satellite IV during 1970.

Saturn is now moving rapidly in towards the Sun, and although it sets an hour or two after the Sun at the beginning of the month, it is not likely to be seen after mid-April. The conjunction of Saturn with Venus on April 11 is referred to in the notes above.

The Innermost Planet. Mercury should be a reasonably easy naked-eye object this month for a few evenings around April 18, but even so it will set not very long after the Sun. Small telescopes will suffice to show the phase, but surface details are extremely difficult to detect.

Maps of Mercury have been drawn up by various observers; until recently the standard chart was that of E. M. Antoniadi, constructed in the 1930s with the aid of the great 33-inch refractor at Meudon Observatory, outside Paris. Antoniadi also gave names to the main dark and bright areas which have come into common use. Recently, G. N. Katterfeld, of the U.S.S.R., has published a new chart, and has revised the nomenclature somewhat.

It used to be thought that Mercury had a captured rotation – that is to say, that it revolved on its axis once for every revolution round the Sun (88 Earth days). This is now thought not to be so. Since the real rotation period, as measured by American radar astronomers, is only about 59 days, every part of Mercury receives sunlight at one time or another; there is no area of permanent day or zone of everlasting night.

However, Mercury is an extremely hostile planet. It is only about 3,000 miles in diameter, which is not a great deal larger than the Moon, and it has virtually no atmosphere. Its surface must be violently heated during the long day, and we cannot picture any form of life which could survive there. Moreover, it must be constantly bombarded by lethal radiations. Whether any manned expeditions will be dispatched to Mercury in the future remains to be seen, but they are likely to be postponed until at least the 22nd century.

It was once thought that another planet moved round the Sun, closer-in than Mercury. It was even given a name, Vulcan; and Urbain Le Verrier, the great last-century French astronomer, believed in its existence. However, further investigations have been entirely negative, and it now seems certain that Vulcan is a myth.

Hydra. During April evenings much of the southern aspect is occupied by the huge, sprawling constellation of Hydra, the Watersnake. Now that Argo Navis has been cut up, Hydra is the largest single constellation in the sky; its 'head' lies near Cancer, and its 'tail' stretches almost as far as Libra. Yet despite its tremendous area, Hydra has only one bright star; this is the reddish second-magnitude Alphard, known as the 'Solitary One' because there are no other prominent stars anywhere near it. There is also a comparative paucity of interesting telescope objects, so that as well as being the largest constellation Hydra is also one of the dullest.

Nine Years of Space-Flight. On April 12, 1961, the first space-flight took place. Yuri Gagarin, in *Vostok 1*, completed a full circuit round the Earth, and landed safely in the pre-arranged position. This feat marked the start of the space era; Gagarin had shown conclusively that Man need not remain chained to Earth.

Events have moved dramatically since that time, and it is a tragedy that Gagarin has not been able to play a full role. In early 1968 he was piloting a jet-aircraft on a practice flight when the machine went out of control, killing both Gagarin and his co-pilot. It is fitting that a statue should have been erected in his honour at the spot where he made his historic landing; his death was regretted all over the world.

May

New Moon: May 5 *Full Moon:* May 21

Mercury is in inferior conjunction on May 9, and although the planet is not otherwise visible this month, it will on this occasion pass in transit across the face of the Sun. A transit in May is rather unusual, and in this case is almost central, beginning at sunrise and lasting for nearly eight hours. This phenomenon is not visible to the naked eye, but those with adequate optical means will find some details in the notes below.

Venus is an evening star, setting about 2½ hours after sunset. It is now well north of the equator and passes Aldebaran on May 6 and Mars on May 9. Both of these conjunctions occur in daylight hours, and although Venus is easily seen in the twilight sky (magnitude −3·4), it will be far more difficult to find either Mars or Aldebaran without some optical aid.

Mars is now well north of the equator in Taurus and sets north of west about two hours after sunset. It passes 6 degrees north of Aldebaran on May 3 and will be close to Venus on the evenings of May 9 and 10, but Mars is now only of magnitude +1·9 and will be difficult to see in the bright sky.

Jupiter is still a brilliant evening star, moving retrograde in Virgo and setting about an hour before sunrise. Magnitude −2·0.

Saturn is in conjunction on May 2 and will not be visible for the greater part of the month. At the end of May it moves out from the Sun to become a morning star, rising about an hour before sunrise.

Neptune is at opposition on May 21 at a distance of 2,725 million miles (4,385 million km.). The planet is not visible to the naked eye (magnitude +7·7), but a small telescope will show it as a greenish disk. The apparent path of Neptune during the year is shown on the diagram on page 60.

The transit of Mercury. The inferior planets Mercury and Venus can both come between the Earth and the Sun, but because their orbits are inclined to the ecliptic they will, in most cases, pass either north or south of the Sun at inferior conjunction. They can only appear in transit across the face of the Sun when inferior conjunction occurs very close to one of the nodes of the orbit. In the case of Mercury the ascending node (where the planet crosses the ecliptic on its journey northwards) lies in longitude 48 degrees, and the Earth is at this longitude about November 10; similarly the Earth is at the descending node in longitude 228 degrees about May 9. If inferior conjunction occurs on either of these dates there will be a transit of the planet; but since the Sun presents a sizable disk of about half a degree in diameter, there is a certain range of dates which will still allow the planet to be seen somewhere on the Sun's disk. This range is much smaller at a May transit than it is in November, and as a result there are fewer May transits than November ones; in the present century there are ten in November as compared with four in May. The cause of this effect lies in the eccentric orbit of Mercury, the planet being nearer to the Earth at the descending node in May than it is at the ascending node in November. This increases the parallax (the apparent displacement of the planet as seen from the Earth) and the apparent motion of the planet, and so reduces the range. We can calculate the limiting conditions at both nodes, and these are best expressed in the form of time limits. Thus we find that at a May transit there is a range of 1·85 days on either side of the node, i.e. a total range of 3·7 days; while at a November transit the total range is as much as 7·9 days. Now from the periods of revolution of Mercury and the Earth we find that

29 periods of Mercury = 7 sidereal years − 5·7 days
54 = 13 +2·0 days
137 = 33 −1·7 days

Thus transits can be repeated at intervals of 7, 13, or 33 years, provided that the error in days falls within the range limits given above. We then see that two transits 7 years apart are possible in November but not in May; the other two periods (as well as some others, e.g. 46 years) can occur at both nodes. It is this absence of the 7-year period that restricts the May transits; in the present century there have been May transits in 1924, 1937, 1957, 1970, and there is no other during this century. The November transits took place in 1907, 1914, 1927, 1940, 1953, 1960, and the next will be in 1973.

The transit on 1970 May 9 begins at 4^h 19^m G.M.T.; this is roughly the time of sunrise in southern England, but a few minutes after sunrise in Scotland. Since both Mercury and the Earth are moving in the same direction about the Sun, the apparent motion of Mercury is quite slow, and since this transit is almost central, it lasts until 12^h 13^m. The tiny black dot, which is all that can be seen of Mercury, is best viewed by projecting the image of the Sun formed by a small telescope on a white card; *on no account should the Sun be viewed through the telescope* unless special filters are used.

Transits of Venus are very rare. In this case the range of dates is very small, since Venus comes so much nearer to the Earth; they take place at the ascending node about December 9 and at the descending node about June 7. Only five transits of Venus have ever been seen – those of 1639, 1761, 1769, 1874, and 1882. They occur at present in pairs, one near the north pole of the Sun, the other to the south, at an interval of 8 years, each pair being followed by an interval of more than a century. The next pair of transits of Venus will not be seen until the years 2004 and 2012, both being in June. Transits of Venus have been used in the past in attempts to measure the distance of the Earth from Venus, and hence from the Sun. These measurements were not entirely successful, and better methods have now replaced them (see *Yearbook* for 1964).

June

New Moon: June 4 *Full Moon:* June 19

Solstice: June 21

Mercury is at greatest western elongation on June 5 (24 degrees), but will then be too low to be seen in the bright dawn sky.

Venus grows a little brighter as an evening star (magnitude −3·4 to −3·5) and sets north of west about two to three hours after sunset.

Mars now begins to set earlier each evening to the north of west, and by the end of June is above the horizon for only an hour after sunset. As it is now only of the second magnitude, it will be difficult to see the planet in the bright twilight.

Jupiter is still an evening star, but fades during the month to magnitude −1·7. Its retrograde motion in Virgo is now quite slow, and it reaches a stationary point on June 24, about 4 degrees north-east of Spica. After this, the planet moves direct again, and it sets just after midnight at the end of June.

Saturn is now a morning star, moving direct in the eastern part of Aries and rising about 2 hours before sunrise at the end of the month. At this time of year the sky is not really dark, and the planet (magnitude +0·5) will be difficult to locate.

An Astronomical Anniversary. Jupiter is still a prominent object in the evening sky this month, and users of small telescopes will be watching it together with its four bright satellites Io, Europa, Ganymede, and Callisto. It is interesting to recall that these names were given to the Jovian satellites by Simon Mayr (also known as Mayer or Marius), who observed the satellites telescopically in 1609–10, and may actually have recorded them before Galileo did so.

Marius was born in 1570, 400 years ago. His family lived at Gunzerhausen, in Germany; he studied astronomy and astrology under Tycho Brahe and Kepler, and became Court Astronomer to the Margrave of Brandenburg. Whether he actually discovered the Jovian satellites, or whether he heard news of Galileo's observations of them, is a matter for debate. Galileo, predictably, was infuriated when Marius claimed priority–and he was also irritated when Kepler refused to sever all friendly relations with Marius.

Naturally, Galileo would not use the names which Marius suggested, and for many years the proper names were seldom used; strictly speaking they are still unofficial. The fifth satellite, discovered by Barnard in 1892, is sometimes called Amalthea, a name due to Camille Flammerion; the remaining seven satellites are unnamed, though proper names proposed some years ago by Marsden are coming into use.

Whether or not Marius was the first to see the four satellites, he can certainly be credited with the discovery of the Andromeda Galaxy, which he saw telescopically in 1612 and described as looking like a candle-flame shining through a horn. He died in 1624.

Wide Double Stars. Double stars are very common in the sky. Rather surprisingly at first sight, very few pairs are due to chance line-of-sight effects; most are true binary systems, with the components moving round their common centre of gravity. With close pairs the revolution period may be very short, and there are, of course, many binaries whose components are too close together to be seen individually, so that they are detected only by spectroscopic methods – unless they happen to be eclipsing systems such as Beta Lyræ, where the components must be almost in contact.

With very wide pairs the mutual revolution is to all intents and purposes undetectable, because the period may amount to many millions of years. This is the case with the two main components of Epsilon Lyræ, the famous multiple star close beside Vega. Keen-sighted persons can split the pair without much difficulty, and a small telescope shows that each component is again double.

Gamma Virginis, in the Y of Virgo, is a good example of a wide, easy pair. The components are almost exactly equal in brilliancy (magnitude 3¾), and a small telescope will separate them. However, the separation is becoming steadily less, and by the end of the century Gamma Virginis will appear single except in giant telescopes. It is worth recalling, too, the case of Castor, which in early Victorian times was a magnificent wide pair; it has closed up since, and is no longer easily separable in small telescopes. Moreover, it will become steadily more difficult for the next century or so.

Theta Serpentis, in the Serpent's body (Cauda), is a splendid example of a wide, easy pair. It is easily found, because it lies almost along the line of Delta, Eta, and Theta Aquilæ; it is separable with any small telescope, and again the components are equal. The period is immensely long, and there will be no obvious change in the pair over the span of a human lifetime. Much the same applies to Nu Draconis, in the Dragon's head. Of course, the most famous binary pair in the whole sky is Mizar, or Zeta Ursæ Majoris, in the Great Bear; there can be no star-gazer, however casual, who has not looked at it. Alcor is a member of the Mizar system, but a very remote one.

It is worth noting that the brilliant blue Vega has a 12th-magnitude companion. Here, for once, we are dealing with an optical pair, not a binary; the companion has no connection with Vega, and is much more distant.

Coma Berenices. Moonless evenings in June provide a good time to identify the little constellation of Coma Berenices, or Berenice's Hair, the subject of a charming old legend. There are no bright stars in the group, but there are many faint ones, and the general impression is that of a large, extended star-cluster. Telescopically the area is very rich, and there are many galaxies spread through the constellation. Coma lies roughly between Alkaid, the end star in the tail of the Great Bear, and the triangle in Leo of which Denebola (Beta Leonis) is the brightest member.

July

New Moon: July 3 *Full Moon:* July 18

Earth is at aphelion (farthest from the Sun) on July 4, when its distance will be 94,500,000 miles (152,100,000 km).

Mercury will not be seen during the month; it is in superior conjunction on July 6.

Venus is now moving rapidly south and sets earlier each evening. It is growing brighter (magnitude −3·5 to −3·7) but by the end of July it sets about 1½ hours after sunset.

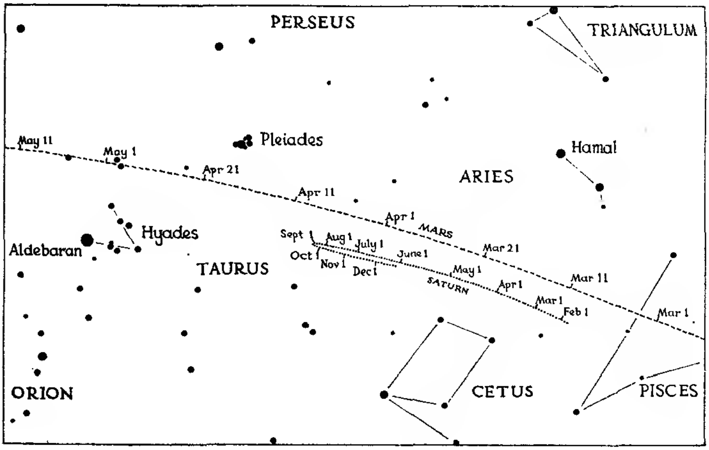
Mars is now approaching conjunction and is not likely to be seen as it sets only a few minutes after the Sun.

Jupiter is an evening star setting before midnight at the end of the month. It is now moving direct in Virgo and its brightness is still further reduced to magnitude −1·6.

Saturn rises north of east at midnight in mid-July. By the end of the month the sky will be growing darker, and the planet is bright enough (magnitude +0·5) to be seen in the eastern part of Aries, moving towards the border with Taurus.

Low Stars. It is a constant source of regret to Europeans (and to New Yorkers) that some of the most interesting objects in the sky, such as the Clouds of Magellan and the rich fields in Argo, never rise above the horizon. It is rather interesting to work out how far south one can see. Theoretically, nothing is easier; all that need be done is to subtract one's latitude from 90 degrees. For instance, consider the southernmost point of Britain, Lizard Point, where the latitude is (to the nearest degree) N50°. 90 − 50 = 40; therefore, a star north of declination +40° will be circumpolar and will never set, while no star south of declination −40° will ever rise. However, we must take the effects of atmospheric refraction into account – and we must also bear in mind that a star which merely grazes the horizon is unlikely to be seen even under excellent conditions.

Consider Canopus, which is second only to Sirius in apparent brilliancy (really, of course, it is an extremely luminous yellow supergiant, whereas the nearby Sirius is a run-of-the-mill Main Sequence star). The declination is −52° 40′, which we may take for our present purpose as −53°. 90−53=37, so we must go down to latitude N.37° to see it. Canopus can never rise from New York (latitude N.40°), but it can be seen from Los Angeles (N.34°), though it will always be very low down.



Saturn, 1970

The case of Gamma Crucis, in the Southern Cross, is interesting. Its declination is −56° 50′, so that the limiting latitude for its visibility should be N.32° 10′. It cannot quite rise from Los Angeles, but apparently there are cases of its having been seen from Palomar, because of the uplift caused by atmospheric refraction.

Fomalhaut, in the Southern Fish (decl. −29° 53′) can become quite prominent from London, but from Thurso in North Scotland (N.58° 36′) its theoretical altitude can never be as much as 2°! Another interesting test is Lambda Scorpionis, the bright star in the Scorpion's sting. Here the declination is −37°, so that it can rise from latitudes south of N.53°, and it should be visible from the Lizard (N.50°). From New York (N.40° 20′) it can attain quite a respectable altitude, and from the southern United States the whole of Scorpio is very prominent indeed. (The version 'Scorpio' still persists, though 'Scorpius' is the official and the more correct name.)

The Perseids. The Perseid meteor shower attains its peak during the first part of August, but the official beginning of the display is July 27, and so it is worth starting to look out for early Perseids during the last week in July. Unlike the Leonids, the Perseids are remarkably consistent; they never fail to provide a good display, and in 1970 there will be no interference from moonlight.

Visual studies of meteors have been largely superseded by radar methods, but are still of value. More important, however, is the photography of meteor spectra, and this is a branch of research that can be tackled by the serious amateur provided that he has the right equipment – together with almost infinite patience! It requires many hours of photographic watch to trap one meteor spectrum, but some enthusiasts, notably H. B. Ridley (former Director of the Meteor Section of the British Astronomical Association) have been pleasingly successful.

The Sun at its Smallest! Because the Earth reaches aphelion on July 4, the Sun appears slightly smaller than is the case in northern winter, when the distance separating the Earth from the Sun is about 3,000,000 miles less. Of course, the difference is not readily detectable with the naked eye (and in any case, it is most unwise to look straight at the Sun), but solar observers have to allow for it.

The solar maximum of 1968 was much less violent than that of the preceding cycle, and even at its greatest peak the activity was only about half what it had been in 1957. By mid-1970 we may expect the number of spot-groups to have been considerably reduced, and there will also be fewer flares and associated phenomena.

August

New Moon: August 2 and 31 *Full Moon:* August 17

Mercury is at greatest eastern elongation on August 16 (27 degrees) as an evening star, but will not be at a sufficient altitude to be seen in the twilight sky.

Venus is growing noticeably brighter (magnitude −3·7 to −4·0), and sets almost due west rather more than an hour after sunset. Its apparent path at this time is shown in the diagram on page 60, and it will be seen that it passes very close to Spica on August 31.

Mars is in conjunction on August 2, after which it moves west of the Sun to become a morning star. By the end of August it rises more than an hour before the Sun, and will then be in Leo, close to Regulus, but the planet is only a second magnitude object, and is not likely to be seen in the dawn sky.

Jupiter is an evening star in Virgo, and sets about two hours after the Sun. Magnitude −1·6 to −1·4.

Saturn rises before midnight at the beginning of the month, and may be seen in a dark sky. It is moving more slowly as it approaches a stationary point, and towards the end of August it passes into Taurus, some degrees to the south and west of the Pleiades.

A partial eclipse of the Moon will take place on August 17, about 41 per cent of the Moon's disk being covered by the shadow of the Earth. For further details, see notes on page 96.

An annular eclipse of the Sun on August 31–September 1 will be visible only in the South Pacific Ocean.

The Perseids. As usual, the Perseid meteor shower will be prominent during the first half of the month, and will be worth watching. Photographic enthusiasts may reasonably expect to trap quite a number of meteors simply by leaving their camera shutters open, aiming the camera toward the radiant.

The Lunar Eclipses. There are no total eclipses of the Moon in 1970, but the partial eclipse of August 17 will be quite interesting, inasmuch as over 40 per cent of the disk will be in shadow. Lunar eclipses are not so spectacular or so important as eclipses of the Sun, and now that the Moon has been reached by probe vehicles their importance is still further reduced, but at least they are fascinating to watch – and to photograph!

Chi Cygni. Chi Cygni, the famous long-period variable in the Swan, is one of the most interesting members of its class. It has a tremendous magnitude range; at its brightest it may rise above magnitude 4, but at minimum it drops to below 14, so that it becomes a very difficult object indeed so far as the average amateur is concerned. The period is about 407 days.

Maximum is due near the end of August 1970, so throughout the month the star should be an easy binocular object – even if this proves to be a faint maximum. It is easy to identify, since the fourth-magnitude Eta Cygni, between Gamma (in the middle of the Cross) and Beta or Albireo (the lovely coloured double star) lies close to it. The variability of Chi Cygni was discovered as long ago as 1686, by G. Kirch, and it has been closely studied ever since. Like so many long-period variables, it is very red, and the colour is easily detectable with binoculars, though not with the naked eye.

The Milky Way. Moonless nights in August provide an ideal opportunity to admire the beauty of the Milky Way, which is at its best, and stretches in a magnificent band from one horizon to the other. It passes through constellations such as Sagittarius. Aquila, Cygnus, Cassiopeia, and Perseus through to Auriga.

It is not surprising that the Milky Way has been discussed since very early times; under good conditions it cannot possibly be overlooked, even though city-dwellers, with their light skies, may not be able to see it. (Trying to observe the night sky from the middle of a city such as London, Manchester, or New York is a hopeless business.) There are many legends associated with it, but not until telescopes were invented did astronomers realize that it is made up of stars.

It was Sir William Herschel who first recognized the true nature of the Milky Way, though a few earlier writers had hinted at it. To Herschel, the star-system was a flattened disk, with the Sun close to the mid-point, so that the Milky Way was a line of sight effect; when looking along the main plane of the system, we would naturally see many stars in approximately the same direction. It is now known that Herschel was correct in principle, but wrong in detail. The Sun is not near the middle of the Galaxy; it is some 25,000 to 30,000 light-years away from the galactic nucleus. The diameter of the main part of the Galaxy is about 100,000 light-years.

The actual nucleus is not visible, because there is too much insterstellar material in the way; we are in much the position of a man standing in Parliament Square on a foggy night, trying to see the dial of Big Ben. However, radio waves are not blocked, and we have considerable information about the central regions of the Galaxy. The direction of the nucleus is toward the lovely star-clouds in Sagittarius, which are always rather inconveniently low as seen from Britain, but are better placed from the southern United States. The owner of a pair of binoculars or a small, rich-field telescope can spend many enjoyable hours in sweeping over the Sagittarius region.

In fact the very richest part of the Milky Way lies in the south, near Crux, but there are rich areas also in the north, notably in Cygnus. Here, too, we find dark nebulæ, visible only because they block out the light of the stars beyond. Herschel regarded these dark nebulæ as 'holes in the heavens', but, understandably, he was mistaken. The most spectacular dark nebula is the Coal-Sack in Crux, but there is another excellent example in Cygnus.

September

Full Moon: September 15 *New Moon:* September 30

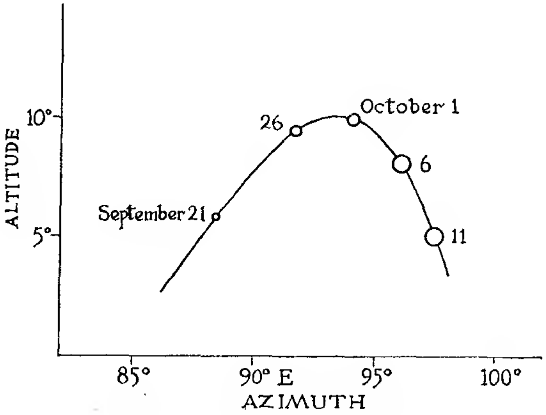
Equinox: September 23

Mercury is in inferior conjunction on September 12 and will not be visible for the first three weeks of the month. On September 28 the planet is at greatest western elongation (18 degrees) and is then well placed in the east as a morning star. The diagram shows the changes in altitude and azimuth of Mercury on successive mornings when the Sun is 6 degrees below the horizon – this is about 35 minutes before sunrise at this season. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is much brighter after the date of western elongation. The planet Mars is in the same neighbourhood, but will be too faint to be seen in the dawn sky.

Venus is at greatest eastern elongation on September 1 (46 degrees), but it is then well south of the equator and low in the sky, so that it sets less than an hour after sunset. Venus passes 5 degrees south of Jupiter on September 14, but there is little risk of confusion, Venus being much the brighter of the two (magnitudes: Venus −4·2, Jupiter −1·4). The apparent path of Venus during this period is shown on the diagram on page 60.

Mars rises about two hours before sunrise below the figure of Leo, but it is still only of magnitude +2·0, and difficult to see in the bright sky; for this reason it is not shown with Venus and Jupiter in the diagram on page 60. Mars is at aphelion on September 30, its distance from the Sun being then about 155 million miles (249 million km). This may be compared with its distance at perihelion last October, about 128 million miles (207 million km) to show the eccentric nature of the orbit of Mars.

Jupiter is still an evening star, setting less than two hours after the Sun and continuing to fade (magnitude −1·4 to −1·3). The planet is in conjunction with Venus on September 14 (see note above) and passes from Virgo into Libra at the end of the month.



Mercury, September to October 1970

Saturn reaches a stationary point on September 5 on the borders of Aries and Taurus. It now rises in mid-evening, and may be seen north of east some degrees below the Pleiades. Saturn is growing steadily brighter (magnitude +0·3 to +0·1) and should be quite easily recognized as there are no other stars so bright in this part of the sky.

Venus as an evening star. Venus has not been at its best during 1970, but will be better placed as a morning star at the end of the year and in the first part of 1971. During September 1970 it reaches its greatest eastern elongation for the year, so that it is an evening object; at the beginning of the month it will appear as a half-disk, and will then become a steadily shrinking crescent.

Venus remains very much a planet of mystery. We know a great deal more about it now than we did before the beginning of the Space Age, but even so it presents us with some curious problems. Before the flight of Mariner II, in 1962, there were several theories about the surface conditions there. Some authorities believed that there might be extensive oceans; others maintained that the surface temperature was too high for liquid water to exist, and that Venus was likely to be an arid dust-desert. The various probes that have been dispatched have confirmed the latter view, and certainly Venus appears to be hopelessly hostile. The rotation period is longer than the planet's 'year' of 224¾ Earth-days, and it seems that the spin is in a retrograde or east-to-west direction. The atmosphere is extremely dense, with a ground pressure perhaps up to 100 times as great as that of the Earth's air at sea level, and there is a tremendous amount of carbon dioxide.

These facts are now reasonably well-established, but we have still to explain why Venus and the Earth are so different. They are of similar size, and indeed have been described as twins; logically they should be in a similar condition, particularly as both lie within the Sun's ecosphere (i.e. the region in which the temperature of a planet may be expected to be tolerable for terrestrial-type life). Yet there proves to be no similarity at all. Venus ought not to have its remarkably dense atmosphere; yet the atmosphere exists, and so far we have to admit that we simply do not know why.

Probes have soft-landed on Venus, and despite all attempts at sterilization it is not inconceivable that contamination may have been introduced. It does not seem that there is much likelihood of this contamination spreading (even if it has been taken there), but uneasy doubts remain.

Before 1962, Venus was widely regarded as a more promising space-target than Mars, but the contrary opinion is now held. Whether manned expeditions will ever be able to land there remains to be seen, but no doubt there will be many unmanned probes launched toward the planet during the 1970s; some of these will soft-land, while others will be put into paths round the planet in order to obtain as much information as possible.

Pegasus. During autumn evenings the southern sky is dominated by Pegasus, the Flying Horse, whose four chief stars make up the famous Square. In fact one of the four, Alpheratz, is officially included in the neighbouring constellation of Andromeda, and is listed as Alpha Andromedæ. There seems no reason for this, particularly as the pattern is more closely allied to Pegasus – and in fact Alpheratz was formerly known as Delta Pegasi.

Alpheratz is of the 2nd magnitude; Alpha Pegasi or Markab is of magnitude 2·6, and Gamma Pegasi or Algenib is 2·9. The fourth star in the Square, Beta Pegasi or Scheat (upper right-hand corner) is variable. Its magnitude range is between about magnitude 2·2 and 2·9, and there is a rough period of around 35 days, but this period is subject to marked irregularities. Scheat is best followed in its fluctuations with the naked eye, and fortunately Markab and Algenib make good comparison stars for it, though due allowance must be made for atmospheric extinction. Binoculars show that Scheat is strongly orange in colour; it has a spectrum of type M, and like many of its class it is an extremely large and luminous super giant.

Incidentally, it is worth looking inside the Square of Pegasus to see how many stars can be seen with the naked eye. There are not nearly so many as might be thought.

October

Full Moon: October 14 *New Moon:* October 30

Mercury may be seen as a morning star during the first week of October (see last month's notes), but after this it moves towards superior conjunction on October 27, and will not be visible.

Venus reaches its greatest brilliancy on October 6 (magnitude −4·3) but it is now far south of the Sun and sets only about half an hour after sunset. The planet moves rapidly in towards conjunction, and is not likely to be seen during the last part of the month.

Mars is a morning star, rising 2 to 3 hours before the Sun in a dark sky, but it is still only of the second magnitude. The diagram on page 88 shows its apparent path from Leo into Virgo during the month.

Jupiter is moving direct in Libra, but now sets shortly after the Sun as it approaches conjunction.

Saturn rises north of east about an hour after sunset. It is now moving retrograde in Taurus, and passes back into Aries at the beginning of October. The magnitude reaches −0·1 at the end of the month (brighter than it was at opposition last year), but the planet will be even brighter when the rings are fully open at the end of 1973.

Magnitudes of the Stars. The division of the stars into grades or magnitudes of apparent brilliancy goes back to very ancient times, but it is only during the past century or so that refined measures have become possible. By general consent, stars of magnitude 1·5 or brighter are classed as being of the 'first magnitude', and many books give lists of them, beginning with Sirius (−1·43) and going down to either Regulus or Castor (+1½). Castor is the 'borderline case' in this unofficial classification.

The two brightest stars are Sirius and Canopus, both of which have minus magnitudes. They are followed, at a respectful distance, by Alpha Centauri, which is not visible in European or North American latitudes. Then follow Arcturus, Capella, Vega, and Rigel, which are approximately equal at around magnitude 0. It is interesting to check upon the values given to these four stars:

Pickering, Harvard Photometry (1890)

Arcturus	0·0
Capella	0·2
Vega	0·2
Rigel	0·3

Pritchard, Nova Oxoniensis (1890)

Rigel	0·1
Capella	0·1
Arcturus	0·3
Vega	0·8

Revised Harvard Photometry, 1898

Vega	0·14
Capella	0·21
Arcturus	0·24
Rigel	0·34

Revised Photometric, 1960

Vega	0·03
Arcturus	0·06
Rigel	0·08
Capella	0·09

Nautical Almanac, 1969

Vega	0·1
Capella	0·2
Arcturus	0·2
Rigel	0·3

Electronic, 1967

Arcturus	−0·06
Vega	0·04
Capella	0·05
Rigel	0·15

Of course, naked-eye comparisons are difficult because Rigel is white, Vega bluish, Capella yellow, and Arcturus orange. It is probably true to say that whichever of these stars is the highest in the sky will also appear the brightest; thus from Britain and the northern United States Rigel is generally much lower than Capella or Arcturus, and will seem correspondingly less brilliant.

Capella and Vega lie on opposite sides of the Pole Star, and at roughly equal distances from it. During October evenings Vega is descending and Capella ascending, so that the two will be at much the same altitude – and comparisons can be made. If the electronic measures are to be trusted, however, the difference between the two is only 1/100 of a magnitude, so that to all intents and purposes the stars are equal. Rigel is thought to be very slightly variable, but the range is less than one-tenth of a magnitude; Arcturus has been suspected of greater fluctuations, but on the whole these seem to be rather improbable.

Argelander, during the last century, drew up a list of 'first-magnitude' stars, and it is interesting to compare the order with that derived by modern methods. In Argelander's list his No. 2, Eta Argûs (or Eta Carinæ) has been omitted, because it is a peculiar kind of variable. For a period between 1830 and 1850 it was one of the brightest stars in the entire sky, and at one stage it surpassed even Canopus, but it has faded since then, and since 1886 it has been invisible to the naked eye. Betelgeux, in Orion, is of course variable, with a range of between about 0·1 and 0·9, so that its position in the series is somewhat arbitrary. During 1968–9 it was rather brighter than Procyon, but markedly inferior to Capella.

Of the first-magnitude stars, Alpha Centauri, Beta Centauri (Agena), Alpha Crucis (Acrux), Beta Crucis, and Achernar are too far south to be seen from Europe or the New York area.

Argelander	*Modern*
1. Sirius	1. Sirius
2. Canopus	2. Canopus
3. Alpha Centauri	3. Alpha Centauri
4. Arcturus	4. Arcturus
5. Rigel	5. Vega
6. Capella	6. Capella
7. Vega	7. Rigel
8. Procyon	8. Procyon
9. Betelgeux	9. Achernar
10. Achernar	10. Betelgeux
11. Aldebaran	11. Agena
12. Agena	12. Altair
13. Acrux	13. Aldebaran
14. Antares	14. Acrux
15. Altair	15. Antares
16. Spica	16. Spica
17. Fomalhaut	17. Fomalhaut
18. Beta Crucis	18. Pollux
19. Pollux	19. Deneb
20. Regulus	20. Beta Crucis
21. Deneb	21. Regulus

The Revised Harvard Photometry values for the remaining stars above magnitude 2 are as follows:

22. Castor (Alpha Geminorum)	1·58	28. Epsilon Carinæ	1·74
23. Gamma Crucis	1·61	29. Epsilon Orionis	1·75
24. Epsilon Canis Majoris	1·63	30. Beta Tauri	1·78
25. Epsilon Ursæ Majoris	1·68	31. Beta Carinæ	1·80
26. Gamma Orionis	1·70	32. Alpha Trianguli Australe	1·88
27. Lambda Scorpionis	1·71	33. Alpha Persei	1·90

34. Eta Ursæ Majoris	1·91
35. Zeta Orionis	1·91
36. Gamma Velorum	1·92
37. Gamma Geminorum	1·93
38. Alpha Ursæ Majoris	1·95
39. Epsilon Sagittarii	1·95
40. Delta Canis Majoris	1·98
41. Beta Canis Majoris	1·99
42. Polaris	1·99

(Polaris is very slightly variable.)

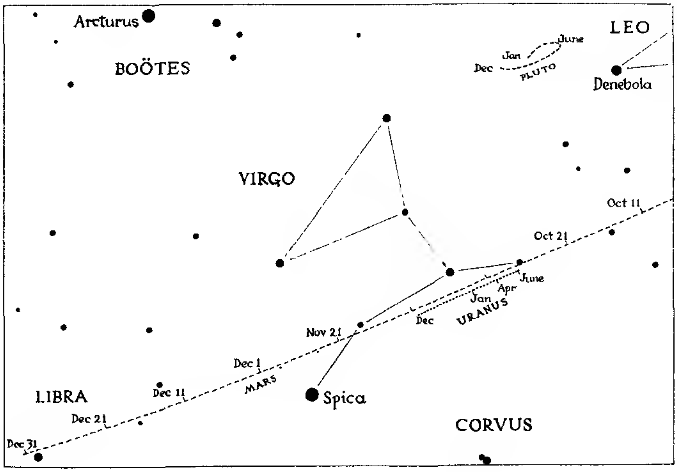
Of these, Gamma Crucis, Epsilon and Beta Carinæ, Alpha Trianguli Australe, Gamma Velorum and Epsilon Sagittarii – as well as Lambda Scorpionis, mentioned earlier – are inaccessible over Europe.

November

Full Moon: November 13 *New Moon:* November 28

Mercury remains too close to the Sun to be seen during the month.

Venus is in inferior conjunction on November 10, and after this date it moves rapidly out from the Sun to appear as a morning star, rising south of east. At the end of November it will be a brilliant object (magnitude −4·2), rising about 2½ hours before sunrise.



Mars, October to December 1970

Mars is now growing a little brighter (magnitude +2·0 to +1·9) and rises in the east at the beginning of November in a dark sky about 3 hours before the Sun. It will be seen just below the figure of Virgo and the diagram shows its conjunction with Uranus on November 7 (Mars $\frac{1}{2}$ degree north) and with Spica (magnitude +1·2) on November 24. The rapid easterly motion of Mars (more than half a degree per day) should be quite noticeable.

Jupiter is in conjunction on November 9, but moves quickly out from the Sun at the end of the month to become a morning star, rising about 1½ hours before sunrise (magnitude −1·3).

Saturn is at opposition on November 11, when it will be at its brightest (magnitude −0·1) and nearest to the Earth (758 million miles, or 1,220 million km.). The planet is now well north of the equator and this is a favourable opportunity for observation; the rings and the largest satellite, Titan, may be seen in a small telescope. The south side of the rings is presented to us, and they are tilted at an angle of about 22 degrees.

The Leonids. Much has been heard recently about the Leonid meteors, which used to give brilliant displays around mid-November every 33 years (1799, 1833, 1866). The displays of 1899 and 1933 did not take place, as the orbit of the main swarm had been perturbed and no longer met the Earth at the critical juncture, but in 1966 the Leonids were back once more, and a superb display was seen – though not, unfortunately, in Europe, since the shower maximum was quite short, and took place during European daylight.

The night of November 16–17 is the important one so far as the Leonids are concerned. Observations were made in 1967 and 1968, but with disappointing results; the Leonids were sparse, although a good many of them were seen. These notes are being written before the 1969 date, but there is no reason to suppose that anything spectacular will be on view; and in 1970 conditions will be even worse, if only because the Moon (four days past Full) will make its presence obvious.

Note that not all meteors seen at this time will be Leonids. Generally the Leonids are bright and swift; but there are also a good many members of the Taurid stream about at this time – and, of course, there are always 'sporadic' meteors, which do not belong to any particular swarm, and which may appear from any direction at any moment.

Saturn at Opposition. Saturn is now well placed for observation. It has moved into Pisces, not far from the border of Aries, so that it is high above the horizon for observers in northern latitudes; and because the rings are opening, the planet is bright. It is about equal to Arcturus and Capella, but the quality of its light is different; instead of being a sparkling point, it looks dull and yellowish, so that we can well understand why the ancients tended to regard it as baleful.

The ring system cannot possibly be seen with the naked eye; though good binoculars will show that there is something unusual about Saturn's shape, a moderate telescope is needed to show the rings well. A 3-inch refractor is adequate, and will also show the gap between the two bright rings (A and B) which is known as Cassini's Division in honour of G. D. Cassini, who discovered it in 1666. The Cassini Division is a real gap, and the same may be true of Encke's Division in the outer ring (A); but various other minor Divisions reported in past years may be more in the nature of 'ripples'. Neither is there any confirmation of an outer dusky ring, known as Ring D, which has been reported on various occasions during the past sixty years.

The principal satellite, Titan, has the distinction of being the only satellite in the Solar System definitely known to have an atmosphere – discovered by Kuiper in 1944, and apparently made up chiefly of methane. A few vague surface markings on Titan have been seen with giant telescopes, but not, of course, with amateur-owned instruments. Of the other satellites, Iapetus is particularly interesting; it is much brighter when west of Saturn than when to the east, so that its shape or reflectivity must be irregular. At its best Iapetus can reach the 9th magnitude, so that it is not a difficult object.

Cetus. The large but rather dull constellation of Cetus, the Whale or Sea-Monster, is now on view in the south. Its most interesting object is the celebrated long-period variable Mira, which was the first variable star to be discovered. The range is from magnitude 1¾ to 9¼, though at some maxima the magnitude never rises above 4. This year maximum occurred in the late summer, when Mira was inconveniently close to the Sun in the sky, and by November the star has faded well below naked-eye visibility, though of course binoculars will show it. Like most long-period variables, Mira is a Red Giant; its spectrum is of type M.

Beta Ceti or Diphda is the brightest star in Cetus. It is slightly below the second magnitude, but there have been reports that it occasionally brightens up temporarily to about magnitude 1½, so that it is worth watching.

Cetus is not in the Zodiac, but it extends toward the ecliptic, and the principal planets can occasionally move into it for brief periods. The only constellation which does intrude into the Zodiacal region, and yet is not ranked as a Zodiacal constellation, is Ophiuchus.

In mythology Cetus was the sea-monster of the Perseus legend, but by now it seems to have been popularly demoted to the status of a harmless whale!

December

Full Moon: December 12 *New Moon:* December 28

Solstice: December 22

Mercury is at greatest eastern elongation on December 10 (21 degrees), when it may be possible to catch a glimpse of the planet as an evening star low in the south-west just after sunset.

Venus is at greatest brilliancy as a morning star (magnitude −4·4) on December 16, when it rises about 4 hours before the Sun. The planets Jupiter and Mars are in the same region of the sky, but there is no possibility of confusion, Venus being much the brightest of the three planets. Venus is moving towards Jupiter, and will pass that planet early in January.

Mars is a morning star and is now beginning to brighten visibly (magnitude +1·9 to +1·6). It rises more than 4 hours before the Sun and may be seen in a dark sky in Virgo, passing into Libra in mid-December. The next opposition of Mars in 1971 August will be a particularly favourable one; the planet will then be in Scorpius at its closest to the Earth (35 million miles or 56 million km).

Jupiter is a morning star moving direct in Libra towards the bright stars of Scorpius, and grows a little brighter during the month (magnitude −1·3 to −1·4). It rises in the south-east about 3 hours before sunrise and will be seen near the planet Venus at the end of the month.

Saturn is still visible for most of the night, but sets in the early morning hours. It is moving retrograde in Pisces and is fading a little (magnitude 0·0 to +0·2) but is still easily recognized – a bright star in a dark sky.

The Approach of Mars. Mars has been badly placed throughout 1970, and at the end of the year it is still a long way away, so that it is not a great deal brighter than the Pole Star. However, it is starting to approach us once more, and by next August it will be almost as close to us as it can ever come, so that it will be a magnificent object in the sky. Unfortunately it will lie well south of the celestial equator, so that observers in European or United States latitudes will be somewhat handicapped.

Mars has always been regarded as the most Earthlike of the planets, but our views have changed markedly since the flight of Mariner IV in 1965. It was then that we learned that the surface of the planet is covered with lunar-type craters, and that the atmosphere is much thinner than had been supposed; moreover, the main atmospheric constituent seems to be carbon dioxide rather than nitrogen. The main trouble is that with so tenuous an atmosphere, there may be no effective screen against lethal radiations; and it is not impossible that instead of being a living world, Mars is quite sterile. This was the point of view put forward in the article *Mars: A Sterile Planet?* in the 1969 *Yearbook*. There is no basically new information to add to what was written then, but it is true to say that most astronomers are much less confident about life on Mars than they used to be.

During December 1970 the disk of Mars will be too small for any real detail to be seen with average-sized telescopes, but the planet will brighten up rapidly during the first months of 1971.

U Orionis and SU Tauri. In 1885 the noted Irish amateur astronomer J. E. Gore, using a pair of binoculars, discovered what he thought to be a nova on the border of Orion, not far from the third-magnitude star Zeta Tauri. Careful and continued observations showed that it was not a nova, but a long-period variable; nowadays it is listed as U Orionis.

It is easy to find, because it forms a triangle with the stars Chi^1 and Chi^2 Orionis. At its brightest it may attain magnitude

5·3, so that it is easily visible to the naked eye; at minimum it goes down to about magnitude 12·6, so that a telescope of appreciable size must be used to show it. Like many long-period variables, it is red, with an M-type spectrum.

U Orionis has a period of 372 days. This means that it reaches maximum a week later each year – and for some time now maxima have occurred during the summer, when the star has been too close to the Sun in the sky to be seen at all. This is still the case; and during the present winter the magnitude will be too low for the star to be a binocular object. It should be at minimum during the period between late February and mid-March, though the period is not entirely constant, so that no hard and fast predictions can be made. Incidentally, it lies close to the Beta Lyræ-type variable UW Orionis, which varies between magnitudes 10·9 and 11·8 in a period of 1·008 days.

Not far from U Orionis is a different kind of variable, SU Tauri. This is not so easy to find, and it never becomes so bright; it never rises much above magnitude 9½. For most of the time it stays between magnitudes 9·2 and 9·7, with slight irregular fluctuations, but occasionally it drops down to below magnitude 16, so that it becomes a very difficult object indeed. One can never tell quite when this will happen; there has been no minimum for the past six years, so that another may be due. (Of course, it may already have begun before these notes appear in print.)

SU Tauri belongs to the rare class of variables known, from their prototype, as R Coronæ Borealis variables. Only about two dozen are known, and only R Coronæ itself and SU Tauri are within the reach of most amateur observers in European latitudes. All the stars are characterized by their deep, sudden minima, which can never be predicted; they are rich in carbon, and deficient in hydrogen. We do not know the precise reason for their peculiar behaviour, but we do know that they are uncommon objects; it has been estimated that the whole Galaxy may contain about 100 of them. A general survey of present knowledge about them was given by J. S. Glasby in *Planetarium*, Vol. I, No. 4.

Shadows from Venus? Venus is now a splendid morning object, and will no doubt raise the usual questions as to whether it can have been the Star of Bethlehem. It is so brilliant that it may, under suitable conditions, cast shadows; and these are worth looking for, though they are not, of course, at all conspicuous. This December, Venus, Mars, and Jupiter make the eastern sky really spectacular in the early hours of the morning.

Eclipses, 1970

In 1970 there are four eclipses, two of the Sun and two of the Moon.

1. *A partial eclipse of the Moon* on February 21 of small magnitude – about 5 per cent – visible in the Americas and the Pacific Ocean.
2. *A total eclipse of the Sun* on March 7 with a maximum duration of $3^{m}\ 28^{s}$. The track begins in the Pacific Ocean, crosses Central America and then passes along the eastern seaboard of Georgia and Carolina to cross Newfoundland and end in the Atlantic Ocean west of the British Isles. The eclipse will be visible throughout North America as a partial eclipse.
3. *A partial eclipse of the Moon* on August 17, visible in the British Isles and North America. The eclipse begins at $2^{h}\ 17^{m}$ G.M.T., and at the maximum phase at $3^{h}\ 23^{m}$ the Earth's shadow, to be seen on the northern part of the Moon, will cover about 41 per cent of the Moon's diameter. The eclipse ends at $4^{h}\ 30^{m}$ G.M.T.
4. *An annular eclipse of the Sun* on August 31, of maximum duration $6^{m}\ 44^{s}$. The track lies entirely in the South Pacific Ocean, but a partial eclipse will be seen in New Zealand.

A transit of Mercury on May 9. Some notes on this unusual event will be found on pages 68–69.

Occultations, 1970

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path, and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than 5 degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about 20 degrees a year, a complete revolution taking 18·6 years, during which time all the stars that lie within about 6½ degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star, but only a few of these occultations will be visible at any one place in hours of darkness.

There are only four first-magnitude stars that can be occulted by the Moon; these are Regulus, Aldebaran, Spica, and Antares. In 1970 the series of occultations of Spica comes to an end in January, but Regulus and Antares are occulted each month throughout the year. The occultation of Regulus by the Full Moon on the night of February 21 is described in the note on page 56 and should be well worth observing. The planets Mercury and Venus are also occulted during the year, but these are either not visible in this country, or occur in daylight hours.

Details of occultations of the planets, and of all stars down to magnitude 7·5, as well as possible occultations of stars by planets, are published in the annual *Handbook* of the British Astronomical Association. Similar information applicable to North America is given in the monthly journal *Sky and Telescope.*

Comets in 1970

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the Sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no previous records of the previous appearance of these bodies, and we are unable to follow their wanderings through space. The comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention from astronomers. Unfortunately they are all faint objects, and are recovered and followed by photographic methods using large telescopes. Most of these short-period comets travel in orbits of small inclination which reach out to the orbit of Jupiter, and it is this planet which is mainly responsible for the severe perturbations which many of these comets undergo. Unlike the planets, comets may be seen in any part of the sky, but since their distances from the earth are similar to those of the planets their apparent movements in the sky are also somewhat similar, and some of them may be followed for long periods of time.

Of the comets due to return in 1970, the following are those most likely to be observed:

Comet Tempel-Swift was discovered in 1869 and last seen in 1908. Some recent calculations by Dr B. G. Marsden indicate that the comet was seriously perturbed by Jupiter at alternate revolutions and the original period of 5·5 years has been increased to 6·4 years, with various other changes in the orbit. The calculations show that the comet should return in January.

Comet Johnson was discovered at Johannesburg in 1949 and has been seen at each of its returns. It has a period of 6·8 years and even at perihelion it is still well outside the orbit of Mars.

Comet Slaughter-Burnham was found on plates taken at the Lowell Observatory in Arizona in 1958; it has a period of 11·6 years.

Comet Gale was discovered in 1927 and seen again in 1938 but not since. It has a period of 11 years.

Comet d'Arrest was discovered in 1851 and has been seen at eleven of its returns to the Sun. Its period is 6·7 years, and it was last seen in 1963.

Comet Pons-Winnecke is one of the oldest of the regular comets. Discovered by Pons in 1819, it was found again by Winnecke in 1858 and has been seen at 15 returns. Owing to perturbations its period continues to increase, and it is now 6·3 years, while its inclination has also increased to the large value of 22 degrees.

Comet Jopff was discovered in 1906 and although it was missed in 1912 it has been seen at each subsequent return. Its period is 6·3 years.

Comet Whipple has been seen at each return since its discovery in 1933. Its period is 7·5 years and, like Comet Johnson, it has a very large perihelion distance.

Comet Väisälä has also been seen at each return since its discovery at Turku, Finland, in 1939. It has a period of 10·5 years.

Comet Schwassmann-Wachmann (1) has a nearly circular orbit lying entirely between the orbits of Jupiter and Saturn. It behaves very much like a planet and is visible each year. This comet, which has a period of 16 years, is remarkable because it undergoes changes of brightness, which seem to have some connection with solar activity.

Meteors

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days.

The following table gives some of the more easily observed showers, with their radiants; the effect of moonlight in 1968 is indicated.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	*Notes*
Jan. 3–4	Quadrantids	Jan. 3	$15^h\ 28^m$	+50°	
April 20–22	Lyrids	April 22	$18^h\ 04^m$	+33°	M
July 27–Aug. 17	Perseids	Aug. 12	$3^h\ 04^m$	+58°	
Oct. 15–25	Orionids	Oct. 20–21	$6^h\ 24^m$	+15°	
Oct. 26–Nov. 16	Taurids	Nov. 1–7	$3^h\ 36^m$	+14°	
Nov. 15–17	Leonids	Nov. 16	$10^h\ 08^m$	+22°	M
Dec. 9–14	Geminids	Dec. 13	$7^h\ 28^m$	+32°	M
Dec. 20–22	Ursids	Dec. 22	$14^h\ 28^m$	+76°	

M = moonlight interferes

Minor Planets, 1970

Nearly two thousand minor planets are listed in the catalogues, but of these only the 'big four', Ceres, Pallas, Juno, and Vesta, can reach any considerable brightness, and only the last of these, Vesta, can occasionally be seen with the naked eye. Such an opportunity occurs in 1970, Vesta being at opposition on February 8 at magnitude 6·3; some notes and a diagram showing the position of Vesta at this time will be found on page 56. Of the other three minor planets, Ceres is at opposition on October 24, magnitude 7·0; Pallas on August 29, magnitude 8·9; and Juno on November 14, magnitude 7·2.

Some Events of 1971

ECLIPSES

In 1971 there will be five eclipses, three of the Sun and two of the Moon.

February 10 – a total eclipse of the Moon, visible in Europe, Africa, America, and Australasia.

February 25 – a partial eclipse of the Sun, visible in Europe and Asia.

July 22 – a partial eclipse of the Sun, visible only in Alaska and north-east Asia.

August 6 – a total eclipse of the Moon, visible in Australasia, Asia, Europe, and Africa.

August 20–21 – a partial eclipse of the Sun, visible only in Australasia and the Antarctic.

THE PLANETS

Mercury will be favourably placed as an evening star at eastern elongation on April 1, and as a morning star at western elongation on September 12.

Venus will not be a very conspicuous object in 1971; it will be at western elongation as a morning star on January 20, and after superior conjunction on August 27 it will be an evening star.

Mars makes one of its closest approaches to the Earth at the opposition of August 10, when the planet will be in Capricornus.

Jupiter is at opposition on May 23 in Libra.

Saturn will be found in Taurus and is at opposition on November 25.

Uranus remains in Virgo, and is at opposition on April 1.

Neptune is at opposition on May 23 in Libra.

Pluto is at opposition on March 19.

PART TWO

Article Section

The same general plan has been followed as in previous *Yearbooks*, the theme being 'something for everybody'. Some of our contributors are familiar to *Yearbook* readers, while this year we welcome, for the first time, Commander Hatfield, Dr Ashbrook, and Mr Hindley. Some notes of interest on our contributors will be found on page 204.

On Seeing

COMMANDER H. R. HATFIELD

We all learned at school that the Earth is surrounded by an atmosphere, which consists mainly of nitrogen and oxygen, with a little carbon dioxide and traces of many other elements. About half the mass of this atmosphere lies within 18,000 feet (3½ miles) of the Earth's surface. Measurable traces of it still exist 100,000 feet (19 miles) up. Although at this height no human being could possibly exist without a space-suit, there is sufficient gas there to create enough friction to melt and vaporize any meteor which may be foolish enough to cross the Earth's path.

Our atmosphere also contains a great deal of hydrogen, combined with oxygen in the form of water vapour. Most of this water vapour evaporates from the surface of the oceans under the influence of the hot tropical sun. Being relatively warm, it rises to great heights, and then circulates outward toward both poles. If and when it meets cold air coming from the poles, it cools, changes once more into the familiar water as we know it, and probably falls as rain. The Atlantic depressions that we know so well form along the line where this mixture of warm tropical air and water vapour is undercut by the cold, dry Arctic air, with the result that the British Isles get more than their fair share of cloud and rain. True water vapour is quite transparent; it is there in the gap between the spout of the boiling kettle and the jet of steam. Steam itself, and all clouds and mist, consist of small droplets of water. When a fog lifts, or the clouds clear away under the influence of a warm sun, the quantity of H_2O in the atmosphere remains unchanged; it merely changes its form from a liquid to a gas. About half the mass of water vapour present in the atmosphere lies within 9,000 feet (1¾ miles) of the Earth's surface.

Very little indeed reaches heights much above 40,000 feet (7½ miles).

If this protective blanket of nitrogen, oxygen, and water vapour were not there, Man would be exposed to all sorts of unpleasant radiations and projectiles coming from the Sun and the depths of outer space. Not many people would survive an hour's sunbathing on a warm summer's day, for the pleasant rays of the Sun as we know them would be accompanied by all sorts of unwelcome companions, ranging from gamma- and X-rays to comparatively large and very energetic atomic particles. The solar wind by itself would indeed bring about a change very swiftly indeed! The atmosphere acts partly as an incinerator and partly as a filter. Unpleasant solid objects arriving from space are quickly incinerated; unpleasant radiations are absorbed. In the event, of the radiation which arrives, only a small part – ultraviolet and visible light, some infrared radiation and some radiation at radio frequencies – manages to get through to the Earth's surface; from time to time a small part of a meteorite survives to make a landing; Man himself has just had to exert his talents to the utmost to devise a method of bringing orbiting vehicles back into the atmosphere in one piece.

All this is very pleasant; indeed, it is vital to Man's existence. But the filtering action of the atmosphere has certain effects which, to the astronomer at any rate, are most important.

Consider the telescope depicted in Figure 1. It has been made with the greatest care, and it will resolve an object which subtends only quarter of a second of arc (a tennis ball 40 miles away) with ease. Its maker is justifiably proud of its performance. He would be quite horrified if he were told that he could only look through it provided that someone was allowed to hold a thick piece of glass in front of it. Yet this is in effect what he himself chooses to do when he sets the telescope up on the Earth's surface; furthermore, his piece of glass may well at times change its optical properties without first obtaining permission to do so.

In front of every telescope there is an extra lens, made and put there by a malignant genie. The diameter of this lens will be equal to that of the telescope's objective or primary mirror; its length (or thickness) will be several miles at the very least; its focal length will be so long that it will to all intents and purposes be a cylindrical prism; it will be composed of nitrogen, oxygen, and water vapour, with traces of other elements; it may well have small particles of liquid water and dust buried in it. Worst of all, it will alter its constitution and refractive index as and when the genie pleases. This lens is shown in Figure 1, firmly attached to the telescope: a true parasite. Ordinary people will not notice it; to them it will appear to be just like the rest of the atmosphere which surrounds us. Anyone who has looked through a telescope on one of those crisp nights when the stars are all twinkling will recognize it for what it really is – astronomical Public Enemy No. 1! For this lens controls what is known as the astronomical seeing. If the genie inside it is in a bad mood, he may well stir

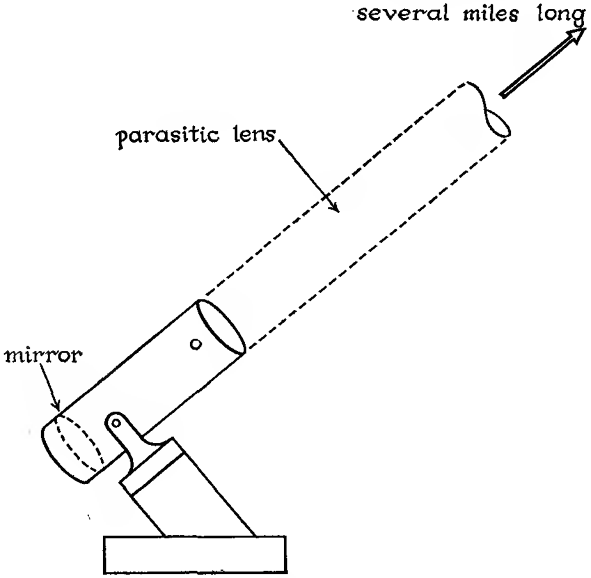


Fig. 1.

up its gaseous interior, substituting water vapour for nitrogen and oxygen several hundred times a second; if he is feeling sleepy, he may stir the brew more gently. In both these cases the astronomer looking through the telescope will not be amused. The really clever observer will invite the water vapour in his atmospheric lens to an all-night party several thousand miles away, give the malignant genie a powerful sleeping-draught, and complete his observations before the nitrogen and oxygen have realized that they have been left out of things. Next morning his friends will congratulate him on his observations, comment on the excellence of the seeing during them, and think no more about it. Only he himself will know the real truth.

The ultimate performance of every telescope, from the smallest 2-inch refractor up to the 200-inch on Palomar, will be controlled and limited by the seeing, which will itself depend entirely upon the qualities of the parasitic atmospheric lens referred to above. The best thing to do, of course, would be to get rid of this lens altogether, by taking the telescope above the atmosphere. An observatory orbiting the Earth, or settled more firmly on the Moon, would be excellent from this optical point of view; it would probably not be very comfortable, and it would certainly be very expensive; no doubt it will appear in due course. If the parasitic lens must be accepted, then it will be wise to make it as short as possible. This is the reason why, where there is any choice, telescopes are built as high up as possible. Height introduces an additional advantage; it gets the telescope above a lot of the water vapour in the atmosphere, and water vapour is a prime ingredient when bad seeing is to be brewed.

What does the poor amateur do, who lives and hopes to observe only a few feet above sea-level? A glance at Figure 2 will tell him.

Suppose, for argument's sake, that the atmosphere is 5 miles high; at this height, a transparent barrier separates it from the near-vacuum of outer space. If the observer looks directly overhead, the parasitic atmospheric lens will be 5 miles long. Not a great deal of it will be prone to the machinations of the malignant genie, who doesn't much like heights, and in any case he will have trouble in stirring up the various atmospheric layers, which will tend to stay at fixed heights. Now let the observer look just above the horizon. The atmospheric lens will be about 200 miles long; the various layers will be running more or less parallel with the axis of the lens, so that the genie will be able to stir quite vigorously, and with good effect, without finding himself too far off the ground.

Clearly, our sea-level observer is likely to obtain his best observations when the object being observed is very high in the sky. In practice, the seeing at an altitude of 60° is not likely to be sensibly worse than that at an altitude of 90°. At 45° things may well be touch and go; and at 20° they are more likely to be go than touch. At that low altitude the prismatic effect is likely to become pronounced, and it will be added to any bad seeing which may otherwise exist. Consider the observer looking at a star on the horizon in Figure 2. Its light will be passing through the various atmospheric layers at an acute angle. These layers will behave like a prism, and the blue light from the star will be refracted more than the red. The result will be that the star's image becomes stretched in the vertical plane, being fringed with red at the bottom and blue at the top.

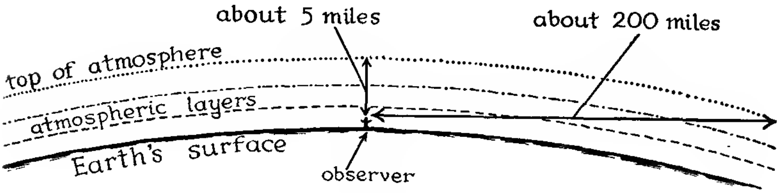


Fig. 2.

In addition to its effect on the seeing and its tendency to produce coloured fringes, the 200-miles' long near-horizontal atmospheric lens will also absorb much more light than its 5-miles' long vertical counterpart.

For all these reasons, low-altitude observations are to be shunned if possible. If they must be made, then a fairly narrow-cut filter placed in the optical train of the telescope will probably improve things, provided that it passes light of sufficient intensity to be seen at all.

Bad seeing usually comes in one of three forms. In the first type, which the author calls jumpy, the malignant genie is quite active. Layers of air having different temperatures and pressures, and different water-vapour contents (and therefore different refractive indices) are passing across the telescope's line of sight in utter confusion. The result, as seen through the eyepiece, is that a star jumps about continually, in a random manner. It may move as much as 3 or 4 seconds of arc from its mean position, with a period of anything between a second or so and perhaps 1/20 of a second. The visual observer will generally be able to follow its movement. Sometimes he may find that he sees a double image for short periods, due to persistence of vision. Jumpy seeing is often associated with the clear skies and cold fronts which follow depressions; it can however occur almost at any time.

If the period of the jumpy seeing decreases much below 1/20 of a second, the human eye can no longer follow the individual jumps. The image of a star becomes expanded, and may well boil; it will probably become very difficult to decide upon the best focus of the eyepiece. A typical planet will turn into an astronomical jellyfish, and this type of seeing has therefore been classified as being of the jellyfish type. In the author's experience the only thing to do with jellyfish seeing is to put the cap on the camera, cover the mirror, and retire indoors for a cup of tea. Fortunately it does not seem to occur nearly so often as the jumpy seeing referred to above.

The third form of bad seeing is bad only insofar as it is not perfect. It occurs whenever the malignant genie is feeling sleepy, and particularly when there is not much water vapour about for him to play with anyway. It will probably be midwinter, calm and very cold, and there may well be snow on the ground; a temperature inversion some hundreds of feet up will help to prevent the various layers from being stirred too vigorously. The result will be that a star's image will still move around, perhaps over a distance of a second or two; but it will move slowly, and will be well-defined at all times. Seeing of this sort should be exploited vigorously, as it is not likely to occur very often at sea-level. It is only a short step removed from the perfect seeing which every astronomer prays for; and given a little encouragement, it may well oblige.

Although the seeing conditions at any one place depend only upon the structure of the atmosphere, their apparent effect varies, depending upon the aperture of the telescope being used. A large-aperture telescope will be looking through an atmospheric lens of equally large diameter. There will be plenty of material in this lens, and the malignant genie will be able to stir it up into a thoroughly nasty brew. The result is likely to be apparent seeing of the jellyfish type; a stellar image may well be expanded into a disk 5″ across. A smaller aperture telescope, and its associated smaller diameter atmospheric lens, will restrict the efforts of the genie. He will still be able to push the stellar image about the same 5″, but he will not be able to work so quickly. The apparent seeing will (apparently) improve to the jumpy type.

Is it therefore sensible to stop down a large aperture telescope when the seeing is bad? The answer is 'No', unless all you want to do is to obtain the resolution attainable with the combination of the smaller aperture *and* the bad seeing. A smaller aperture can never improve the seeing; it can only alter its apparent effect, and this only because it cannot properly resolve the aberrations introduced by the malignant genie. Even when the seeing is quite bad, one can still expect to find fleeting moments when the resolution obtainable with a large aperture is not spoiled. If these moments are not worth waiting for, then the best thing to do is to pack up and go to bed.

So far we have assumed that the seeing is being evaluated only by the human eye and brain. What happens when the eye is replaced by a camera? Clearly the camera will welcome good, steady seeing with open arms. If the image is well defined, but moving around relatively slowly, then results are likely to depend very much upon the times of exposure; it will nearly always be worth while 'having a go' in these conditions. If the seeing is jumpy, the camera should in theory be quite unable to cope with the situation. However, the author has found (to his delight) that in practice, theory is sometimes confounded. Nice sharp images of lunar craters 2½ miles in diameter have been obtained with 3-second exposures, when the craters have been dancing around over an area at least four times their size. Chance has much to do with the result; on occasions two pictures have been taken within one minute in identical fashion; one has been nice and sharp, and the other very blurred. So it would appear that the doubtful photographer should plump for having a go, if the seeing is jumpy. On no occasion when the visual seeing has been of the jellyfish type has the author obtained anything but a jellyfish-like image on the film. The amateur astronomical photographer always hopes that his next photograph will be his best, but his hopes are unlikely to be fulfilled if the seeing is of this type. If a single-lens reflex camera is used, the photographer will be able to pounce upon the fleeting moments of better-than-average seeing when, and if, they arrive. Patience is needed. But there is, in the author's experience, a surprisingly high element of chance. Out of ten photographs of the same object, nine are likely to reflect accurately the photographer's visual estimate of the seeing conditions, but the tenth may quite well be in a superior class of its own.

Bad seeing conditions are often generated many hundreds of feet above the astronomer's head. They may also be generated nearer home. Hot roofs, awkwardly placed chimneys, other people's bonfires, and the exhausts from Diesel trains can all generate enough turbulence in the air to impair the definition in a telescope. People living in built-up areas should not be too much put off by these nuisances, however. A little water can work wonders,* and conditions are not likely to be too bad all the time.

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* Please note that the author can accept no responsibility for the effects of water that may be applied to other people's bonfires!

If there is any choice, then an amateur's telescope should be erected some way away from the nearest building, preferably in a grass field or amongst low bushes, and with grassy or wooded country lying in the most important observing direction.

In all the talk above, the author has purposely avoided any mention of the bad seeing conditions which may sometimes be generated within the tube of a telescope – partly because tube-currents and their effects could form the subject matter for a separate essay, but mainly because his own telescopes, being quite tubeless, have never been worried by them.

Transits of Mercury

Dr JOSEPH ASHBROOK

For nearly eight hours on May 9, 1970, a rare and beautiful celestial spectacle will be visible from most of the Earth, as Mercury passes across the face of the Sun. Even a modest-size telescope will show the planet then as a very small, very black sharp-edged circular disk, slowly working its way eastward across the bright solar disk. This phenomenon has not occurred for a decade. In fact, during the whole 20th century there are to be only fourteen transits of Mercury, if we include the two grazing events of May 1937 and November 1999.

This rarity is due to the fact that Mercury's orbit plane is inclined 7·0° to the Earth's orbital plane, whereas the Sun's disk appears to us only 0·5° across. Thus when Mercury is at inferior conjunction (that is, when it passes on the nearer side of the Sun), it ordinarily goes well north or south of the Sun, missing it completely. The line along which the two orbit planes intersect is called Mercury's line of nodes. Each year, the Earth passes through Mercury's ascending node on November 10 and through the descending node on May 9. (These dates drift slowly later from century to century.) As a result, a transit of Mercury across the Sun is possible only when the planet arrives at its node within a few days of the corresponding date.

On the average, there are thirteen transits of Mercury per century, but there are about twice as many November ones as May. This predominance is readily seen from the table (on page 124) of all the transits during the five centuries from A.D. 1605 to A.D. 2108. In this table, all dates are expressed in the Gregorian calendar (New Style), and the times, which are of mid-transit, are counted from Greenwich midnight.

The reason for the relative abundance of November transits is straightforward. At a November transit, Mercury is quite near the perihelion point of its rather elliptical orbit; at a May transit it is near aphelion, and therefore considerably nearer the Earth. Therefore, the chance of any one May inferior conjunction resulting in a transit is reduced. Otherwise stated, Mercury must be considerably closer to its node for a May transit to happen than for a November transit.

Inspection of the dates in this table shows that in most cases one transit will be followed by another one 46 years later (plus 0, 1, or 2 days, depending on how many leap years intervene). Thus, the November transit of 1605 is followed by others in the years 1651, 1697, 1743, and so on through 2078. Similarly, the transit of 1615 belongs to the sequence 1661, 1707, 1753, 1799, 1845, 1891, and 1937. But here this series ends, for on each successive transit Mercury's path across the Sun's disk has been farther south, until in 1937 it has just missed.

The reason for this 46-year cycle is that 191 revolutions of Mercury around the Sun take almost the same time as 46 of the Earth. After the lapse of 46 years, the Sun, Mercury, and Earth have returned to very nearly the same configuration as before.

There is another, more accurate repetition cycle of slightly over 217 years. If we measure both planet's motions relative to Mercury's line of nodes, 901 revolutions of Mercury very nearly equal 217 of the Earth. Simon Newcomb gives this cycle as $79{,}260^{d}\ 6^{h}\ 24^{m}$ for November transits and $79{,}260^{d}\ 2^{h}\ 10^{m}$ for May transits.

A telescope must be used for detecting Mercury during a transit, because its angular diameter at a May passage is 12″ and at a November one only 10″ – both well beyond the capability of the unaided eye. Nevertheless, before telescopes came into astronomical use in the early 17th century, Tycho Brahe and others believed that Mercury's diameter was as great as 2′. Kepler published a tract in 1609 at Leipzig asserting that he had actually seen the planet against the Sun on May 28, 1607. He cited two earlier instances: the 'black spot seen in the sun' in

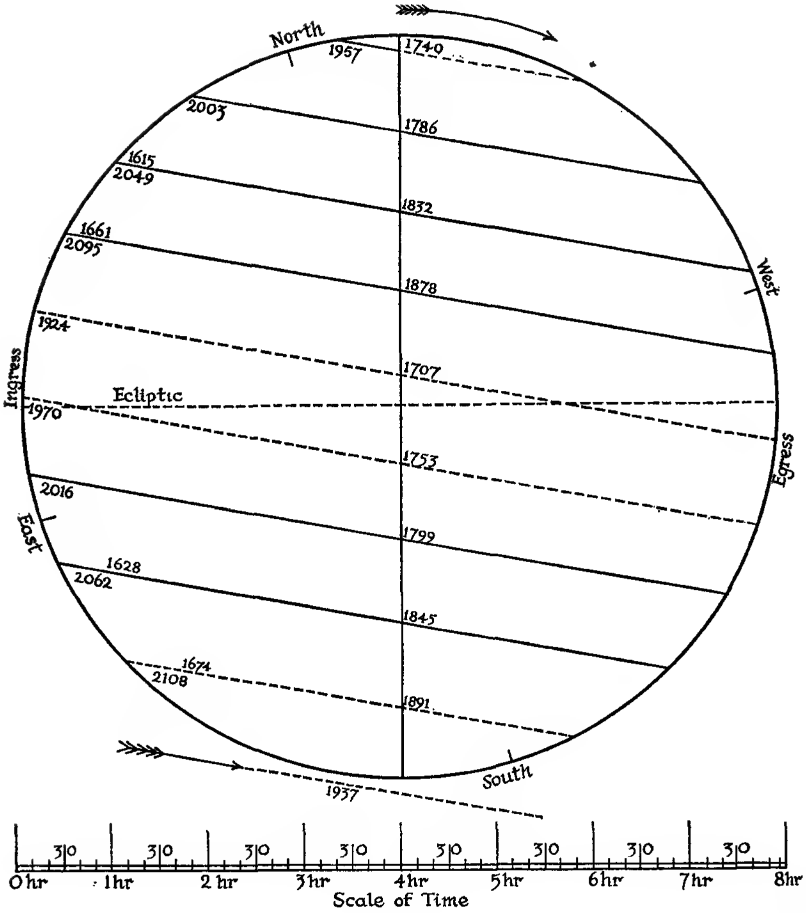
North
1957
1740
2003
1786
1615
2049
1832
1661
2095
1878
West
1924
1707
Ingress
Ecliptic
1970
1753
Egress
2016
1799
East
1628
2062
1845
1674
2108
1891
South
1937
30
0hr
1hr
2 hr
3hr
4hr
5hr
6hr
7hr
8hr
Scale of Time

Fig. 1.

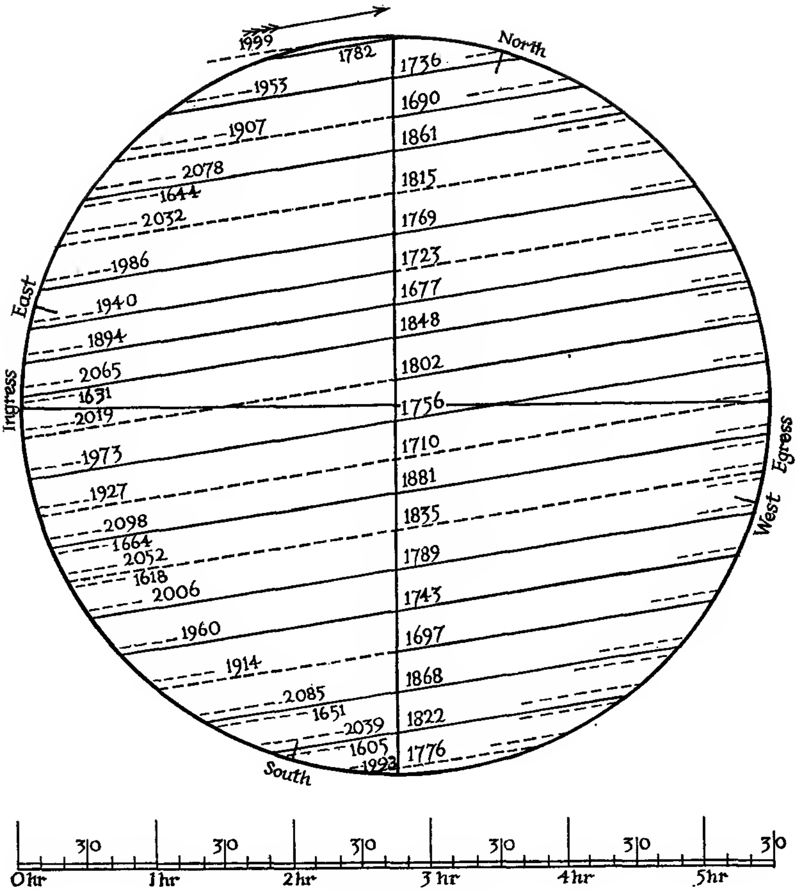
1999
1782
North
1736
1953
1690
1907
1861
2078
1644
1815
2032
1769
1986
1723
East
1677
1940
1848
1894
1802
2065
1631
Ingress
1756
2019
1710
1973
Egress
1881
1927
1835
West
2098
1664
2052
1789
1618
2006
1743
1960
1697
1914
1868
2085
1651
1822
2039
1605
1776
1993
South
30
30
30
30
30
30
30
0 hr
1 hr
2 hr
3 hr
4 hr
5 hr
Scale of Time

Fig. 2.

March 807, which Einhard mentioned among the prodigies presaging the death of Charlemagne, and an observation in 1161 by the Arab scientist and philosopher Averroes. All three instances may confidently be attributed to naked-eye sunspots, particularly as Einhard says his spot remained visible for seven or eight days.

Kepler, however, redemmed himself by afterwards making the first successful prediction of a transit of Mercury in his *Rudolphine Tables* (1627). Two years later he published a pamphlet to call astronomers' attention to the forthcoming transits of Mercury on November 7, 1631, and of Venus on December 6, 1631 (this latter event was, however, invisible from western Europe).

Pierre Gassendi at Paris was the only known observer of the 1631 passage of Mercury, which he viewed by projecting the telescopic image on a white screen in a darkened room. Not trusting the accuracy of Kepler's prediction, he had begun watching two days earlier. Five hours after the scheduled time, he caught sight of Mercury as an unexpectedly small dot, and followed it to egress. Not having a good clock, he could not make timings of scientific value, yet he was able to measure the diameter of Mercury during transit. His result, 12·8″ for the planet as seen from a distance of one astronomical unit, was twice the true value, an indication of the poor optical performance of his primitive telescope.

The next transit, in 1644, was invisible from Europe and went unseen by anyone. A young Englishman, Jeremiah Shakerley, predicted that the passage of Mercury on November 3, 1651, would be visible from India, and he made the long voyage to Surat to observe it. The following transit, that of May 3, 1661, was seen at Danzig by the famous selenographer Hevelius, who projected the Sun's image on a screen for this purpose. Neither Shakerley nor Hevelius saw the planet until it had entered upon the solar disk, for their predictions were too crude to tell just when and where to look for the first notch in the Sun's edge.

The first man to watch the entire course of a transit of Mercury was Edmond Halley, later the second Astronomer Royal and discoverer of the periodicity of the comet that bears his name.

At the age of 20 he had been sent at government expense from England to the island of St. Helena for the purpose of observing the positions of southern stars. Despite the astronomically unfavourable weather, he managed to compile a useful catalogue of 360 stars that won for him renown as the 'austral Tycho'. There, too, he observed the transit of November 7, 1677, with a non-achromatic refractor 24 feet long, recording these local apparent times for its four contacts, which he described thus:

I	9:26:17 a.m.	Sun's limb first indented by Mercury
II	9:27:30 a.m.	Mercury entirely upon the Sun's disk
III	2:40:08 p.m.	Mercury internally tangent to Sun
IV	2:41:54 p.m.	Sun's limb again unbroken.

These observations by Halley, although imperfect, are the oldest that Simon Newcomb has used in his comprehensive and monumental analysis of Mercury transit timings up to 1881. At the 1677 event, last contact was also timed by J. C. Gallet at Avignon, France, and by Richard Townley in Lancashire, but only very roughly.

During the century following, as the quality of telescopes and clocks improved, and as astronomers became more numerous, the observation of these phenomena spread over Europe and around the world. Thus the transit of 1690 was watched from as remote a site as Canton, China, by the French missionary Fontenoy. The first transit of Mercury to be observed at Greenwich was that of November 9, 1723, again by Halley. Apparently the first American to see a passage of this planet across the Sun's disk was Professor John Winthrop of Harvard University, on May 2, 1740. That afternoon, he watched Mercury's ingress, but the Sun set before egress. This transit was a notable one for its short duration of only 2½ hours, the planet passing only a short distance within the Sun's south limb. Winthrop also observed the transit of November 5, 1743.

Until after the middle of the 18th century, the typical instrument used for viewing transits of Mercury was a non-achromatic refractor of small aperture but 20 or 30 feet long. Having only a single-lens objective glass, such a primitive telescope would give images with false coloured borders and more or less fuzziness. Small reflecting telescopes with speculum-metal mirrors were coming into limited use around 1750. It was not until about 1780 that achromatic refractors came into general employment as observatory workhorses for eclipses, comets, transits, and Jupiter's satellites. While these telescopes approached modern instruments of the same size in performance, they seldom exceeded 3 or 4 inches in aperture until after 1800.

The limited optical means used by the run of old observers is worth remembering in connection with the remarkable phenomena they often noted during transits of Mercury. One such popular effect was a central bright spot on the planet while it was crossing the Sun, seen by J. P. Wurzelbau on November 3, 1697, at Nürnberg; on November 9, 1802 by J. H. Fritsch, a clergyman at Quedlinburg, Germany; on May 5, 1832, by G. Moll at Utrecht; and indistinctly on November 9, 1848, at Princeton, New Jersey, by Stephen Alexander. The bright spot is seldom if ever mentioned by modern astronomers using good equipment, and many other observers recorded their failure to detect it. It may safely be dismissed as an occasional subjective effect, evidently due to contrast.

The same may be said for the luminous aureole bordering the black disk of Mercury, seen by J. Cassini at Thury, France (1736), E. Prosperin at Uppsala, Sweden (1786), H. Flaugergues at Viviers, France (1786, 1789, and 1799), Fritsch (1802), and by some others. On the other hand, a dark or dusky halo was announced by J. H. Schröter and C. L. Harding at Lillienthal, Germany (1799) and by Simms and Riddle at Greenwich Observatory (1832).

The strong suggestion that all such appearances were illusions can be underlined by three descriptions of the transit of November 5, 1868. William Huggins noted a *bright* border to Mercury, having a width of one-fifth the planet's diameter; E. Liais found *no* trace of an atmosphere, from careful inspection with three telescopes; while T. von Oppolzer described a *greyish* atmosphere

3″ wide around the planet, an appearance he suspected to be a deception. It might also be mentioned that the only observer who ever saw Mercury in transit to be accompanied by a satellite, as long ago as 1832, also saw an atmospheric border!

Clearly, the old accounts of central bright spots and bright or dark haloes belong to the folklore of astronomy rather than in its storehouse of fact. The general experience with modern instruments is much better described by Sir William Herschel's impression of Mercury during the transit of 1802 as a black, perfectly round dot having no ring, and with solar surface detail visible up to the very edge of the planet.

The main reason, until very recently, why astronomers conscientiously observed transits of Mercury was that careful timings of the contacts could determine the position of the planet with considerable accuracy. The *geometrical* definitions of the four contacts are: (I) disk of Mercury externally tangent to that of the Sun at the beginning of transit; (II) internal tangency of the disks at ingress; (III) internal tangency at egress; and (IV) external tangency at egress, as Mercury quits the Sun completely. Obviously contact (I) cannot be timed with much accuracy, because when a visual observer first can see a notch in the Sun's limb, the moment of true tangency is already past. It was the timing of the two interior contacts (II) and (III) on which the main reliance was placed for determining Mercury's position, and hence the corrections to its orbital elements.

By analysing the contact timings at the transits up to 1848, the great French astronomer U. J. Leverrier discovered a discrepancy between the observed and predicted rates of the motion of Mercury's perihelion. The gravitational attraction of the other planets on Mercury causes the perihelion point of its orbit to move about 1·5° eastward per century. This effect is a bodily rotation of the orbit as a whole in its own plane. Leverrier in 1859 found that the observed rate of the perihelion motion was 38″ per century more than the predicted rate. Seemingly small, this discrepancy was too large to be explained away as due to observational errors, or to uncertainties in the perturbing planets' masses. Leverrier's own explanation was that some unknown intra-Mercurial planet was disturbing the orbit of Mercury. But the 'Vulcan' that Lescarbault claimed to have seen crossing the Sun on March 26, 1859, was quickly discredited. Later, photographs of the Sun's surroundings during total solar eclipses gave a convincing demonstration that no intra-Mercurial planet of appreciable size can exist.

For many years, the excess motion of Mercury's perihelion remained among the most important unsolved problems facing mathematical astronomers. Many attempted explanations were carefully tested, but all failed, until it finally became realized that a more fundamental approach than Newtonian mechanics was needed. Albert Einstein's general theory of relativity in 1916 turned out to predict exactly such an effect, amounting to $43{\cdot}03'' \pm 0{\cdot}03''$ according to G. M. Clemence's calculation in 1947. This is in excellent agreement with Clemence's value of $42{\cdot}56'' \pm 0{\cdot}94''$ for the observed excess motion. In fact, this Mercury perihelion effect is generally considered as the most accurate of all observational confirmations of general relativity. (Very recently, an American physicist, R. H. Dicke, has proposed an alternative explanation in terms of his scalar-tensor theory of gravitation. It still awaits a decisive independent test.)

During the 20th century, the transits of Mercury have lost much of their value for studies of the planet's motion. Today, meridian-circle observations are more useful than timings of the transits, both because of their greater number and their much improved accuracy. The precision with which the contacts can be clocked is limited because these are not sharply defined events. Under ordinary conditions of seeing, the Sun's limb is undulating, making it very difficult to judge at which moment the disks of Mercury and the Sun are exactly tangent. Also, at an interior contact, it is not unusual for a 'black drop' or dark ligament to join the adjacent limbs of the Sun and planet, persisting for sometimes many seconds during which the observer remains undecided whether or not geometrical contact has in fact observed.

As a good demonstration of these uncertainties, let us take the very widely observed transit of May 6, 1878. Many American observers were instructed by the U.S. Naval Observatory to describe the specific appearances during ingress and egress, for an elaborate analysis of their timings that was conducted by H. M. Paul. Here is a portion of his results for contact (II), in which he gives these averages for the observed times.

Observer's Description	*Ave. G.M.T.*	*No. Obs.*
Geometric contact (with black drop)	$3^h\ 15^m\ 26{\cdot}7^s$	4
Geometric contact (no black drop)	3 15 42·6	8
First glimmer of light behind planet	3 15 49·4	12
Breaking of black drop	3 15 52·8	7
Closing of line of light	3 15 57·0	14

Simon Newcomb's critical rediscussion of 85 American timings of contact (II) at this transit gave $3^h\ 15^m\ 50{\cdot}7^s$ as the most probable overall average, whereas from 73 European observations he found $3^h\ 15^m\ 47{\cdot}3^s$. He concluded ruefully: 'That the means of two so large bodies of observers should differ by 3 seconds shows it hopeless to expect a probable error of less than 2 seconds in the best possible results from observation.'

A similar conservative appraisal was made by Clemence of the numerous contact timings secured at the transit of November 11, 1940, when a systematic campaign was again conducted. This astronomer has pointed out that visual timings of contacts retain some value for fixing the longitude of the node of Mercury's orbit. The observed duration of a transit, that is to say the length of the chord across the solar disk that the planet travels, is in principle a very sensitive measure of the planet's position in its orbit relative to its node. In practice, however, the length of the chord also involves corrections to the semi-diameters of the Sun and Mercury, corrections that depend upon the actual observing conditions. To evaluate all the unknowns will require the combination of many heavily observed transits. Thus there is some scientific value to carefully made and reported amateur timings of contacts at the May 9, 1970, transit and later ones.

But the limitations inherent in contact observations can be avoided by taking a large number of photographs, say 100, with a long-focus telescope during the course of a transit, for accurate measurements of the position of Mercury relative to the Sun's centre. Such a programme was carried out at Mount Wilson Observatory for the 1940 transit, and again at Goethe Link Observatory in Indiana in 1953.

A transit of Mercury is a very advantageous opportunity for measuring the angular diameter of the planet, for at such a time its disk is perfectly circular, without any complications from phase. Many such measurements were made during the 19th-century transits with the filar micrometer, which, however, is subject to systematic errors from irradiation because of the bright background.

During the transit of November 14, 1953, the French planetologist, Audouin Dollfus, determined the diameter of Mercury with an improved double-image micrometer, attached to a telescope on top of the Eiffel Tower in Paris. Such a micrometer produces two images whose relative position can be controlled with a precision screw, so that by bringing the two images of a planet into tangency its diameter can be measured. Modern double-image micrometers are relatively free from systematic errors. Though Dollfus' work was hampered by clouds, he was able to obtain a fairly good result, corresponding to 6·45″ for Mercury as seen from one astronomical unit.

An even better technique, suggested by the famous Danish astronomer Ejnar Hertzsprung, was successfully tried out at the transit of November 7, 1960. His idea is noteworthy for its clean simplicity. A small diaphragm of accurately known size is used with a photo-electric photometer on a long-focus telescope. One measurement is made of the amount of light transmitted when Mercury is centred in the diaphragm with a ring of Sun around it; a second measurement is made on the neighbouring solar background. Because Mercury's disk can be regarded as perfectly black, its diameter relative to the aperture is easily computed.

At the request of the International Astronomical Union, several observatories in 1960 made special determinations of

Mercury's size with double-image micrometers and by the Hertzsprung method. From five such series, Dollfus deduced that the diameter of Mercury as seen from one astronomical unit is 6·67″ ± 0·05″.

The variety of possible ways of observing a passage of Mercury extends beyond what has been described above. For example, on May 11, 1937, when the planet passed just outside the southern limit of the Sun – a near miss – B. Lyot at Pic du Midi Observatory in France used a coronagraph to photograph its tiny black disk in silhouette against the solar corona.

W. M. Witchell had a unique experience at the Royal Greenwich Observatory on November 7, 1914, while he was observing the Sun's co-ordinates with the Airy transit circle. Mercury was at the time working its way across the solar disk just as the Sun was crossing the meridian. With an assistant to read the zenith-distance microscopes, Mr Witchell was able to make a complete determination of the right ascension and declination of both bodies.

For the amateur astronomer, it is worth mentioning that a 3-inch refractor armed with a power of 100 and a suitable dark filter is entirely adequate for making good observations of the coming transit of Mercury on May 9, 1970. Whatever programme he chooses, it should include careful timings of the contacts. The recorded times should be to the second, and should be accompanied by a concise statement of the particular appearances to which they refer. In any event, the timepiece should be checked against radio time signals or their equivalent. The geographical position of the observer needs to be known to within a mile or so, if his timings are to be analysed. The other observations that may be made during this and future transits are limited only by the ingenuity of the astronomer, professional or amateur.

THE TRANSITS OF MERCURY: 1605–2108

All dates are Gregorian (New Style); Universal times are of mid-transit

1605	Nov.	1	21^{h}	1782	Nov.	12	15^{h}	1953	Nov.	14	17^{h}
1615	May	3	10	1786	May	4	6	1957	May	6	1
1618	Nov.	4	14	1789	Nov.	5	15	1960	Nov.	7	17
1628	May	6	3	1799	May	7	13	1970	May	9	8
1631	Nov.	7	7	1802	Nov.	9	9	1973	Nov.	10	11
1644	Nov.	9	1	1815	Nov.	12	3	1986	Nov.	13	4
1651	Nov.	3	1	1822	Nov.	5	2	1993	Nov.	6	4
1661	May	3	17	1832	May	5	12	1999	Nov.	15	22
1664	Nov.	4	19	1835	Nov.	7	20	2003	May	7	8
1674	May	7	0	1845	May	8	20	2006	Nov.	8	22
1677	Nov.	7	12	1848	Nov.	9	14	2016	May	9	15
1690	Nov.	10	6	1861	Nov.	12	8	2019	Nov.	11	15
1697	Nov.	3	6	1868	Nov.	5	7	2032	Nov.	13	9
1707	May	5	23	1878	May	6	19	2039	Nov.	7	9
1710	Nov.	6	23	1881	Nov.	8	1	2049	May	7	15
1723	Nov.	9	17	1891	May	10	2	2052	Nov.	9	3
1736	Nov.	11	10	1894	Nov.	10	19	2062	May	10	22
1740	May	12	23	1907	Nov.	14	12	2065	Nov.	11	20
1743	Nov.	5	10	1914	Nov.	7	12	2078	Nov.	14	14
1753	May	6	6	1924	May	8	2	2085	Nov.	7	14
1756	Nov.	7	4	1927	Nov.	10	6	2095	May	8	21
1769	Nov.	9	22	1937	May	11	9*	2098	Nov.	10	7
1776	Nov.	2	22	1940	Nov.	11	23	2108	May	12	4

* Near miss.

Navigation and Astronomy

HENRY BRINTON

Astronomy these days is losing something of its glory. The oldest of the sciences, it has been, unless one counts abstract mathematics as a science, the branch of learning which had no possible practical value whatever. It offered man the pursuit of knowledge in its purest form. For some time now, it has descended largely into the field of fundamental physics, a branch of science which can hardly be called unpractical, since it has given us the ultimate achievement of the human race: the power to destroy itself.

For all its lofty past, astronomy began as a tool of astrology, and has always supported its poor relation: the skill of navigation. From the earliest times, and in a most rough and ready way, men have used the heavenly bodies to guide their journeys about the Earth. In the last few centuries, the crude early approximations have gradually developed into a skill of considerable sophistication. It was the demands of the early navigators which encouraged and rewarded the craft of clockmakers like Harrison, and which were responsible for the foundation of the Royal Observatory at Greenwich.

Accurate timekeeping is an essential for astro-navigation; but it is surprising to find how competently seamen found their way around the globe from the time of the great voyages of discovery to the end of the 18th century, when accurate clocks became available. Latitude is easily determined from a measurement of the maximum height of the Sun at local noon; and, with this information, the desired destination can be reached by a rather less than direct route. All that is necessary is to know the latitude of one's destination. One then aims by dead reckoning to arrive at the required latitude some way to the east or west of a destination which lies to the west or east, and then sail along the parallel until the destination is reached.

With a sextant, even a small island can be found in this way; but there were some tragedies in the early days, resulting from the cruder instruments in use. For rough and ready navigation, it is easy to make oneself a simple astrolabe which will do the job. This consists essentially of a circle marked in degrees, with a sighting arm pivoted in the centre (Fig. 1). Gravity will provide an artificial horizon, and one merely has to sight the lower edge of the Sun along the arm, and read off its elevation. Naturally there are several corrections to make, such as allowing for the

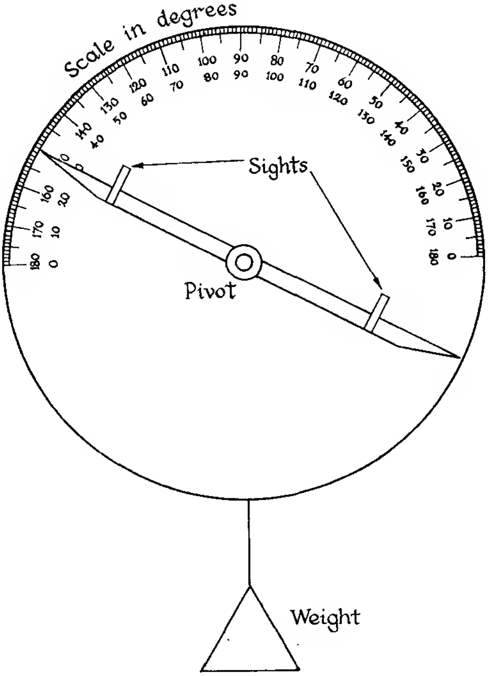

Fig. 1.

semi-diameter of the Sun; but, with an astrolabe, one is spared allowing for the height of the eye above sea-level.

If one makes such a reading on the day of an equinox, when the Sun is vertical over the equator, it is obvious that, for every degree one goes due north or south of the equator, the Sun will appear to be one degree below the zenith. One's latitude, in fact, is equal to the angular distance of the Sun from the zenith. The same calculation is made on any day of the year by the additional correction of adding or subtracting the Sun's declination north or south of the equator. It is not necessary to know one's latitude, and hence the time of local noon, since one can take a series of readings, and calculate for the moment when the Sun's elevation reaches a maximum.

The next step of fixing longitude requires an accurate clock and some difficult calculations, though these have been smoothed out by the most modern navigational tables. In any case, the complexity of the calculations is only due to the fact that the Earth is spherical, and distances require spherical trigonometry to work them out. If one were prepared to navigate with nothing but a large globe and a pair of compasses, a dim-witted child could do the job. In fact, Columbus would doubtless have given a great deal for the chance to navigate in this way.

The Sun, of course, is just a rather unimportant star. Its one special value for navigational purposes is that it can be seen, when it is seen at all, at the same time as the horizon. To be weighed against this virtue is the drawback that it alters constantly in declination. A star, though it can only be seen at the same time as the horizon for limited periods at dusk and dawn, has the advantage that it always keeps the same declination – that is, of course, subject over very long periods to the alterations due to procession and nutation.

Since any given star always has the same declination, it follows that its zenith position follows a parallel of latitude. If its declination is, say, 20° North, it is always at the zenith at some point on this latitude, 20° North. Latitude can be found from it, just as from the Sun, by measuring its maximum altitude – if it is visible for long enough. To find longitude, one needs the time, so that, from the almanac, one can determine the exact point on the Earth, along the given parallel of latitude, it is at the zenith point at the moment when a sight is taken.

Having found its zenith point at the moment, we merely

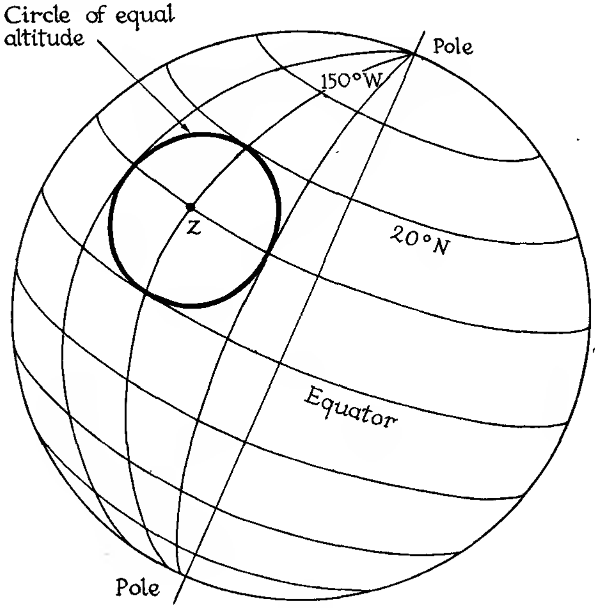

Fig. 2.

measure its altitude above the horizon, and correct the reading for the height of the eye above the horizon, and for refraction. Now, clearly, every degree that the star in question is below the zenith, means that we are that number of degrees away from the zenith position of the star, though it may be in *any* direction, as measured by the angle subtended at the centre of the earth. In other words, we are somewhere on a circle of equal altitude.

Suppose, for instance, that the zenith point of the star measured is at 20°N and 15°W, and that the corrected altitude of the star is 65°. This means that its zenith distance is 25°, and we are therefore somewhere on a circle whose centre is the zenith position of 20°N and 15°W and whose radius is 25 × 60 nautical miles, since a nautical mile is equal to one minute of the Earth's circumference.

We can, if we wish, draw such a circle on our globe. We need not even measure the distance of the radius with a flexible ruler; we can just set the compasses by extending them to the distance of 25° measured from the latitudes marked on the globe itself. Figure 2 marks such a position. In practice, we can get a fair fix from this one circle and a dead reckoning position. If, however, we wish to be more accurate, we can proceed to repeat the process by taking a fix on a different star, not too close to the original one. A second circle of equal altitude can now be drawn on the globe, and our position exactly determined by the point of intersection of the two circles. In fact, they will intersect at two places; but dead reckoning will tell us which of the two points is the correct one.

If, by any chance, one started with absolutely no knowledge of one's position, or if the points of intersection of the two circles were very close together, we can come to a final determination by taking the altitude of a third star, or, generally, by a latitude reading from a transit.

Really, nothing could be easier or simpler than this form of navigation, which would be vastly superior to the methods used by the great explorers; but, for modern exact navigation, one has to have resource to spherical trigonometry, which is straightforward but long-winded. If in Figure 3 we take Z as the zenith point of the star, S as the position of the ship, and P as the pole, p is equal to the zenith distance of the star and s the angular polar distance of the star (90° minus its latitude). If we now take z as the dead reckoning polar distance of the ship, we have a triangle with three known sides and can find the angle SPZ, which, added to (or subtracted from) the longitude of the zenith point of the star, will give the longitude of the ship. By repeating the process, assuming a latitude for the ship slightly different from the dead reckoning position, we can deduce a different longitude for the ship, which will be somewhere on the line joining the two indicated positions of the ship. The line is really part of a great circle, but, for practical purposes, it can be drawn as a straight line on the chart. By taking a reading from a second star, we shall get a second position line, and the actual position of the ship will be indicated by the point of intersection of the two position lines.

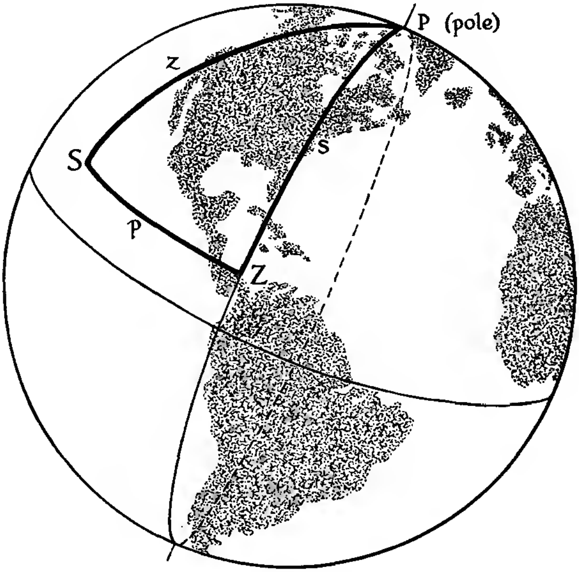

Fig. 3.

As has been pointed out, these involved calculations have been obviated by the most modern nautical tables; but, in any case, astro-navigation is becoming little more than an auxiliary method of navigation, and is being displaced by various electronic and inertial systems. The Decca system, for instance, where it is available, will actually keep a pen moving over the chart, tracing the position of the ship or plane with great accuracy.

Astro-navigation, however, in refined forms, is by no means dead. As this short article is being written, three men are on the way to orbit the Moon. They will be using a form of inertial guidance, as well as radio aids; but they are also using a three dimensional form of astro-navigation, coupled to a computer. As men reach farther out into space and travel greater distances, the phenomenal accuracy demanded will be beyond the capacity of inertial systems and limited radio guidance from the single source of the earth. Astro-navigation, whilst it is falling into disuse for terrestrial purposes, has a great future in space travel. The poor relation of astronomy will come into its own as a tool of astronomical exploration.

Why go into Space?

HOWARD MILES

Since the turn of the century, science and technology have advanced to such an extent that even the wildest dreams of the Victorian era have tended to become accepted as everyday affairs. It is interesting to recall that it was only in 1901 that the first signals were transmitted across the Atlantic from Newfoundland to Cornwall, and to compare this feat with the recent sending of TV pictures of the Martian surface over distances of the order of 150 million miles. It was only in 1903 that the Wright brothers succeeded in flying a heavier-than-air machine for a short distance; yet now, rockets fly at speeds as high as 25,000 miles per hour. Although Tsiolkovskii in the Soviet Union, Goddard in the United States, and Oberth in Germany had done much pioneering work in the field of rockets and space travel, the rocket era really started with the launching of V2 rockets against the British Isles during the last war. These sensational items of their times representing aeronautics, communications, and electronics, when combined together form the basic requirements for all space projects. It is easy to look back and comment that these events have led to other developments besides sending satellites into orbit, but the important point to realize is that at the time of the discovery of some scientific principle or some technological achievement, it is rarely possible to assess accurately how the event will influence the life of man. When Faraday first noticed that an electric current flowing through a wire suspended in a magnetic field caused the wire to move, the fact was noted with interest. In reply to the question: 'This is very interesting, but what use is it?', Faraday asked 'Of what use is a newly born child?' As is well known, this discovery led to the development of electric motors, one of the keystones of our present society.

During the last ten years, man has made his first journeys outside the Earth's atmosphere. It started in 1961 when Yuri Gagarin made his single orbit of the Earth. Four years later, man made his first excursion outside a space capsule, and by 1968 he had freed himself of the Earth's gravity by circling the Moon at a height of 110 kilometres. These manned events were, however, preceded by a large number of instrumented probes each designed for some particular investigation.

At this stage it is natural to consider whether it is worth the cost of carrying out these space experiments, and secondly whether it is necessary. It is the nature of Man to investigate the unknown and then to see if the acquired knowledge can be developed for some purpose. How quickly this is done depends on the need for a particular device. Throughout history there are many examples to show that most progress is made in times of war, or at least when there is a strong need for national defence. This was particularly true in the case of rocket development and the uses to which rockets could be put for military purposes. Nevertheless, in space, much development has taken place in purely scientific investigations, but obviously the spin-off has benefited both the military and civil organizations.

From a scientific point of view, there are two basic reasons why it is advantageous to have laboratories situated above the atmosphere. Anyone looking at a photograph of, say, Jupiter taken by some of the largest telescopes will be struck by the relative lack of detail of surface features if comparison is made with the drawings made of the planet using much smaller instruments. In the latter case, the eye can wait for moments of good seeing and only at these times will detail be recorded. The photographic plate, however, integrates the light intensity falling on the plate over the whole of the exposure period, resulting in the details being recorded at moments of good seeing being drowned by the effects when the seeing is not so good. If, however, a telescope could be placed above the atmosphere, the problem would be overcome and the quality of the photographs improved considerably. This was brought home in a striking manner when photographs of sunspots were obtained using a telescope suspended from a balloon which had been sent up to 80,000 feet.

The atmosphere has another drawback in that it allows only radiation of certain wavelengths to reach the Earth's surface. From a point of view of the existence and evolution of man, this property of the atmosphere is essential because it protects him from the dangerous rays and particles emitted from the Sun. There are two groups of radiation which can penetrate through the atmosphere, the region we call visible light and one part of the spectrum associated with radio waves. It is through these windows that observations of astronomical objects can be made from Earth-based observatories. The only way to make observations at any other wavelength is to set up an observing post above the atmosphere. This can be achieved by either sounding rockets or by satellites, although in the case of the former, only a small fraction of the flight time is available for this purpose. Much initial research and development of experiments is carried out from sounding rockets, but it is the satellite which provides the platform for most of the current research.

Before describing the types of experiments that are being carried out by the hosts of satellites that are being launched, it is instructive to look at two aspects of space activities which are having a marked effect on our lives and which we are tending to take for granted. The first is in the field of communications. It was only a few years ago that the first television pictures were transmitted across the Atlantic and even then it was only possible for a few minutes when the satellite was above the horizon as seen from both the United States and Europe. These *Telstar* and *Relay* satellites were experimental, being used to investigate the use of active satellites for relaying telephone messages and TV signals. They were called 'active' because the signals were received by the satellite, amplified, and then retransmitted. The other type of satellite, the 'passive' type, of which the famous *Echo* balloons are examples, were used as mirrors to reflect the signals. It has been found that the active technique is far more efficient, and so it is not expected that balloons of the *Echo* type will be launched in the future for this particular purpose. Research continued and a third technique using a synchronous orbit has now become well established. This involves putting a satellite in orbit above the equator at a height of about 22,300 miles so that it takes exactly 24 hours to make one revolution of the Earth. This, to an observer on the Earth's surface, gives the impression that the satellite is perched permanently in a stationary point in the sky. If this point is located over the Atlantic Ocean, it will be visible all the time from both Europe and America. Radio telescopes such as the 80-foot diameter dish at Goonhilly Downs, Cornwall, can be pointed permanently at the satellite without having to carry out regular tracking across the sky as was necessary with the earlier types. After the research and development associated with these 'Syncom' satellites came the commercial exploitation in the form of the Communications Satellite Corporation, usually referred to as Comsat, established in 1962 by Act of Congress of the United States. Comsat's first satellite, *Early Bird*, was launched in April 1965, and was able to provide 240 voice channels or a single TV channel. Larger satellites, *Intelsat 1* and *2*, were launched two years later, in positions over the Pacific and Atlantic respectively, thereby forming a world-wide link-up. A second dish has been built at Goonhilly to cope with communications from other parts of the globe. At the moment it is necessary to have large receiving antennæ, because the present satellites are relatively low-powered, but it is most likely that a future generation of commercial satellites will transmit signals strong enough to be picked up by domestic receivers.

The Soviet Union has also developed a communication system but based on a system which is far more suitable for their needs. They use the *Molniya* satellites launched into highly elliptical orbits in which it takes 12 hours to complete one revolution. Over the Russian land mass the satellite is about 24,000 miles high, and so moves very slowly and is above the horizon for a very long time. This system is suitable for countries situated at high latitudes, and so a truly global system may be developed with a combination of both the American synchronous and the Russian systems.

The possibility of using orbiting spacecraft for meteorological purposes was accepted long before the launching of the first Sputnik. From the American point of view this was driven home by the identification of the now familiar whirlpool cloud formation associated with hurricanes seen in photographs taken from sounding rockets. The early experimental *Tiros* weather satellites transmitted pictures of cloud formations, and also information on the infrared radiation from the Earth's surface and the atmosphere. In the earlier launches, information was received only in America, but later versions added a facility known as APT (Automatic Picture Transmission) which enabled countries over which the satellite passed to request the satellite to transmit pictures of the cloud cover in that area directly to that country. The whole process took about 4 minutes. This enabled meteorologists, scattered over many parts of the world and equipped with relatively cheap equipment, to obtain information about local cloud conditions almost immediately.

The large-scale cloud patterns have been used to detect overall change patterns and also to detect the presence and location of hurricanes and other tropical storms much in advance of that possible by the more traditional methods. Apart from the more sensational aspects, they have played an important part in giving a complete world-wide weather picture, the *Tiros* information being used to fill in gaps from areas where few ground-based stations exist.

As with all applications, further uses have become apparent. In 1963 information from *Tiros* enabled accurate predictions to be obtained for the paths of locust swarms, thereby enabling the ground organizations to take the necessary precautions. Another application in an entirely different field illustrates the range of future possibilities. When the area was clear of cloud, it was possible to locate the formation and break-up of ice in the Gulf of St Lawrence enabling more efficient use of the ice-breakers in that area.

The success of the early meteorological and communications satellites has made it necessary to conduct further research into the technological aspects of such satellites, for example, attitude control. It is essential to have the cameras pointing towards the Earth and also the solar panels towards the Sun so as to provide energy to replenish the batteries. This has been achieved in the past by using small attitude-control gas jets, but if a passive technique such as a gravity gradient stabilization method could be used, this would be a distinct advantage. With this kind of problem in mind, the A.T.S. (Applications Technological Satellites) programme was formulated. The A.T.S. programme is very widely based, being designed to investigate spacecraft technology, communications, meteorology, orbital environment as well as spacecraft control techniques. The tremendous achievements of the first three of these A.T.S. satellites have shown how indispensable are orbiting satellites in this technological age. The successful transmissions of V.H.F. communications between land stations, ships, and aircraft, and also of colour TV have shown the potentialities in these directions. *A.T.S. 3*, in synchronous orbit, was moved from 95°W to 85°W to provide time signals for the U.S. Coast and Geodetic Survey cartographers who were remapping the southern Atlantic Islands of South Georgia and Tristan da Cunha. This satellite has also been used successfully in tracking a car travelling at 95 km per hour with an accuracy of ⅓ km. It has also been used in navigation experiments with the U.S. Navy. To illustrate the diversity of uses, it was also used to transmit TV coverage of the Mexican Olympic Games to Goonhilly Downs. Later on it was used to transmit TV pictures from Apollo 7 to Europe.

Side by side with this work has been the satellites connected with E.S.S.A. (Environmental Science Services Administration). This agency is not concerned solely with space vehicles, but also to an understanding of our physical environment, the composition of the Earth, sea, and atmosphere, their interaction and the hazards they present. This is necessary for the defence of life and property against the hazards of Nature, such as hurricanes, floods, and sea waves caused by under-sea volcanic action or earthquakes. The first E.S.S.A. satellites were natural developments of the earlier *Tiros* and *Nimbus* spacecraft. The uses of these satellites can be illustrated by the fact that weather photographs showing the movement and rate of travel of a typhoon as recorded by *ESSA 3* enabled storm warnings to be given to Suva in the Fiji Islands, thus averting a great loss of life. On another occasion the same satellite gave notice of areas of pack-ice in the Antarctic, thus enabling the British Antarctic Survey supply ship to avoid using the Weddell Sea. One series of photographs showed icebergs measuring 72 km by 40 km.

From a financial point of view, the cost of launching and tracking the meteorological satellites is more or less paying for itself. For example, it is estimated that in the United States alone, satellite weather forecasting is saving about $2,500,000 per year in their economy. But in many cases it is difficult to give any meaningful figure. In the autumn of 1968, two Mexican cities were in danger of being flooded by the possible breaking of a nearly completed dam. The authorities had to decide whether or not to open the dam. If the rains continued they would be forced to open the dam, flooding the town of Gomez Palacios, and losing the water needed for agricultural schemes. If they did not open it, there was a grave danger of the dam breaking and flooding, not only Gomez Palacios but also Torreson. Acting on the information from *ESSA 6* that the storm had more or less finished, the authorities kept the dam closed and at the same time made sure of an abundant water supply for its agricultural programme.

The applications and benefits described above have been the result of a deliberate programme, but they could not have been achieved without a tremendous amount of research in other fields. Take for example electronics and the miniaturization of circuits or more accurately, micro-miniaturization. This has been necessary so that the required equipment could be carried in the limited space available and possibly, what is more important, within the weight limitations required by the rockets. Research in this field has been costly; but having achieved it for a particular space programme, the spin-off into many other fields was natural. Micro-miniaturization has made a big impact in the bio-medical field. For example, a light switch activated by the movements of the eye has been adapted for use by paralysed paraplegics to operate motorized wheel-chairs.

Requirements in rocketry have demanded new materials to stand the extremely high temperatures experienced in the motors. These materials are now finding uses in many fields outside space technologies. A plastic pipe, developed for rocket motor casings, is now being used on a large scale in the United States for water and sewer pipes. It is more durable, resistant to corrosion, and six times lighter than conventional pipe materials. The fascinating way in which milk falls away from the surface of non-stick kitchenware illustrates one application of the spin-off which has reached many households. New types of paints have been developed and adopted on a large scale in industry, especially where structures and other surfaces are exposed to extreme conditions.

In the future it is certain that some industrial processes which require, say, vacuum conditions will be carried out in space. The zero gravity conditions existing in an orbiting vehicle would be ideal for the manufacture of high quality ball-bearings. Any application of the future will be the results of investigations which are at the present on the frontiers of knowledge. As has been the case many times in the past, no small part will be attributed to the research carried out by astronomers, and so it is essential that this sphere of research is not curtailed.

Important branches are the study of the near-space regions, solar-terrestrial relationships and the study of the Moon and planets. Progress in all these fields has been considerable and some of the discoveries of immense significance.

Whilst it is generally accepted that instrumented probes can provide much information, it is not so widely accepted that the extra advantage that can be obtained from manned flights is worth the exceptionally large increase in cost. Man has an important rôle to play in space research, and this rôle cannot be replaced by instrumented probes. Instruments cannot think, and cannot make intelligent interpretations of a given situation. They cannot record unexpected phenomena. It is in these capacities that Man is indispensable. The conditions required to put Man into space, keep him alive and return him safely are complex and costly, but even after such a short period of time the spin-off in the medical field has been considerable. The progress in the understanding of heart disease is well known; a technique developed specially for use in space conditions has now been applied to patients suffering from hypertension as well as heart diseases. There is no doubt that many of the medical problems which are causing so much trouble at the present time will be solved or at least understood far better as a result of space medicine. The Soviet Minister for Health stated recently that space medicine promotes the development of fields of knowledge essential for early diagnosis and prevention of diseases on Earth. This has been recognized for some time by both the Americans and Russians. Both have carried out many biological experiments. The Americans have, amongst other things, launched a series of biological satellites to study such phenomena as the effect of zero gravity on wheat seeds, frogs' eggs, and amœbæ. The Russians carried out biological experiments involving tortoises, worms, and insects when their lunar probe *Zond 5* circled the Moon in 1968.

Conditions which exist in the upper regions of the atmosphere are of prime importance. Knowledge of this region was scanty before the space age, and so it was not surprising that within 7 months of the launching of Sputnik 1, Professor Van Allen of the United States reported the first major discovery, the existence of a radiation belt surrounding the Earth at heights above 650 km. Subsequent satellites and space probes have enabled the shape of this belt to be defined, and have also shown the existence of a second belt much farther out. This view has now been modified, so that now it is thought that there is a single belt consisting of two zones differing considerably in their properties but which are linked intimately. Investigations into these belts and to many other aspects of the upper regions of the atmosphere have been carried out by relatively small satellites in the *Explorer* series, launched by NASA. In addition, much has been learned of the frequency of micrometeorites and the intensities of X-rays and gamma-radiation. A similar range of experiments has been carried out by the Soviet Union in their *Cosmos* series. These investigations have provided a fuller understanding of solar-terrestrial relationships, an essential requirement for a warning system to be established when the Earth's magnetic field is distorted, creating difficulties in navigation and communications.

The use of satellites for navigation purposes has great possibilities, and much development work has already been carried out. Techniques using Doppler effects and laser beams have been investigated. The Americans have launched a special series under the code-name *Transit* for developing a system to be used by their Polaris submarines and this has recently been extended to some surface vessels. Accuracies of the order 1/10 km have been achieved; what is more significant is that it is independent of weather conditions.

The ability to obtain positional fixes of high accuracy obviously leads to applications such as map-making and surveying. Special Geodetic satellites have been launched for this purpose.

The American *Imp* series of probes, designed to study the solar wind and related phenomena have provided information on such matters as the effect of the Moon passing through the Earth's magnetospheric tail for about 4 days each month. The results of these particular studies could be of major importance to man.

The second generation of satellites, the orbiting observatories, are much larger versions developed from the *Explorer* series. The Orbiting Solar Observatories (OSO) monitor the Sun from a height of 650 km above the Earth and provide information in the X-ray and U/V regions as well as high resolution spectrograms in the visible region of the spectrum. The directional accuracy achieved is equivalent to holding a penny at a distance of 1 km. Closely allied to these satellites are the Orbiting Geophysical Observatories (OGO) which measure fluctuations in the Earth's magnetic field and atmosphere, linking these with the behaviour of the Sun.

To understand fully the structure of the Earth, and hence apply the acquired knowledge for Man's benefit, it is essential to have available information of the composition and structure of our nearest neighbours. To provide this knowledge much effort has gone into sending probes to these bodies. Much has been written about the sensational events associated with these vehicles. It is possible that by the time these words are read Man will have landed on the Moon and returned to Earth with samples of lunar rocks. Analysis of these will help in the understanding of the Earth's interior.

Very few if any of the achievements mentioned above would have been possible but for the tremendous advances that have been made in computer designs. The miniaturization of this equipment is having a marked effect in many fields outside the space industry, and the impact of small portable units is going to have a revolutionary impact on the life of Man.

Perhaps one of the most surprising aspects of spin-off from the space programme is the technique of planning on a large scale. Any individual space project is so complex, involving a multitude of industries and administrative bodies, that the act of launching a probe at a given time is a major achievement. That this is now accomplished regularly is due in no small way to those who have been concerned with details of planning. This know-how is now being introduced into other fields where detailed planning is essential.

It is impossible to forecast the future. Some people can make intelligent guesses, but one thing is certain. Much that will be taken for granted in the years ahead will be the results of the work which at present is classed as purely scientific research with no apparent applications. Great prospects could open up in the optical industry for the manufacture of large lenses and high quality mirrors, particularly important in astronomy.

The Nature of Comets

KEITH B. HINDLEY

Astronomical events which can be seen with the naked eye can be classified into two groups. The first includes the periods of night and day, the phases of the Moon, and the motions of the Sun and stars across the sky – all every-day events accepted as normal. The second includes eclipses, bright meteors and comets – all unheralded events of a startling nature. Of this latter group, comets are by far the most awe-inspiring, as their visibility often lasts for several weeks. Formerly they were nearly always regarded as evil portents, foretelling death and destruction.

There is no disputing that a Great Comet is a remarkable sight, with a head as bright as Jupiter or Venus, and a hazy tail stretching half-way across the sky. Whilst about one comet a year becomes bright enough to be faintly seen with the naked eye, only about half a dozen really Great Comets are visible every century. This situation, however, has been altered radically in modern times with the invention of the telescope and camera. Modern equipment has enabled astronomers not only to follow naked-eye comets for a much longer period as they faded, but has enabled many faint comets which never become visible to the naked eye to be discovered. Nowadays, about sixteen comets are observed on average every year, but the majority are extremely faint, with only three or four being observable with small amateur telescopes.

The most impressive feature of Great Comets is certainly the tail, which can be up to 180° long (Comet Halley, 1910 II). Unfortunately, the great majority of comets only appear as diffuse disks of light, with little or no tail. This diffuse patch, known as a 'coma', is the hallmark of the comet, and every comet must have had this appearance at some stage or another. Certain asteroids move in comet-like orbits, and it is only this 'fuzzy' appearance, rather like a dimly lit piece of cotton wool that enables the two types of object to be differentiated. Unfortunately, as we shall see later, the dividing line is by no means clear-cut, and it is interesting to speculate on how many 'asteroids' are in fact faint comets with little or no coma, and how many 'comets' are in fact asteroids with a slightly diffuse appearance.

Whilst all comets show a coma, two other features are sometimes visible – a nucleus and a tail. The nucleus is a small, rather faint object located at the centre of the coma. Now, the comæ of most comets brighten in the centre to form the 'central condensation', but this should not be confused with the true nucleus, which is usually star-like and 3–6 magnitudes fainter than the total brightness of the comet. Nuclei are shown by most comets, and usually become more prominent as the comet moves closer to the Sun.

As we have seen, not all comets possess tails, but when present, the tail constitutes one of a comet's most attractive features. Modern work has revealed two types of tail, depending on the type of particles they contain. Some comets have one type, some the other, but bright comets usually show both types at the same time.

Figure 1 shows the main features of a bright comet, and the coma and nucleus are indicated. The two types of tail are also shown; a long narrow one composed of bright streamers, and a curved diffuse one lagging behind the comet as it moves. The spectroscope reveals that the long straight tail is composed of glowing ionized gas molecules that leave the region of the head with velocities of from 10 to 1,000 km/sec. The orbital motion of the comet is slow compared with this, and so the gas tail effectively points directly away from the Sun. The diffuse curved tail is found to have a spectrum of reflected sunlight, due to myriads of tiny solid particles. These move away from the Sun with velocities of from 2 to 100 km/sec, and so tend to lag behind the gas tail. It is clear that the coma and nucleus (together making up the head of the comet) are the sources of supply of the material that maintains the tails.

One interesting feature is that no matter which direction the comet is moving, the tails always point away from the Sun. Thus, when the comet is moving sunwards, the tail lags behind; but when the comet is moving away from the Sun, it actually moves tail-first. It is clear that material in the head is reacting to some solar influence and is being repelled directly away from the Sun. It is now known that the repulsive force is supplied by the 'solar-wind', a constant flow outwards from the Sun of particles, atoms, and the full range of electromagnetic waves, from X-rays through ultra-violet, visible, and infrared light to radio waves. This wind exerts an outward pressure on material in the head of a comet;

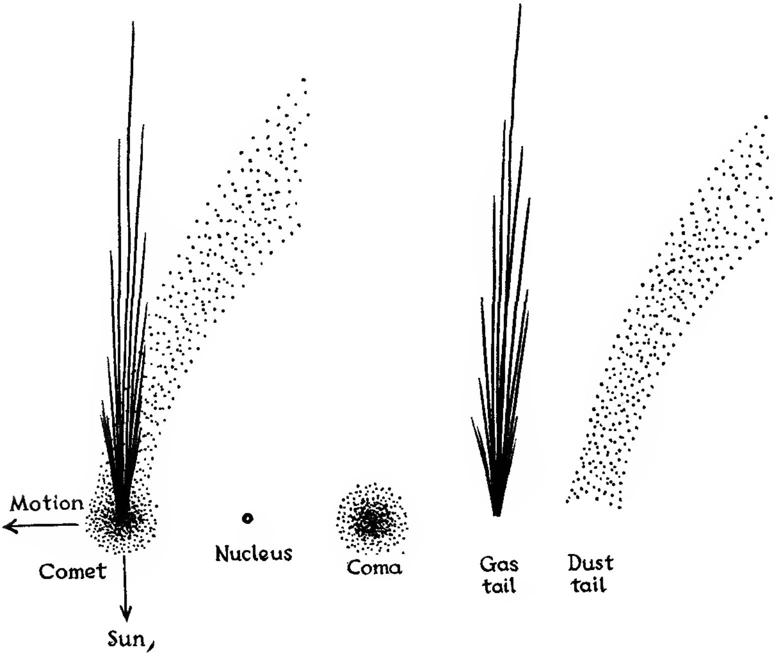

Fig. 1.

and the smaller the particle, the greater the pressure. Atoms of gas are so light that they are whisked away smartly to form the gas tail, whereas tiny solid dust particles are swept away at a more leisurely pace to produce the dust tail.

Once comets are investigated in any detail, it becomes apparent that the Sun is the dominating influence in their behaviour. They are only observable in those parts of their orbits (usually very elongated ellipses with the Sun at one focus) which are relatively close to the Sun. Their overall brightness is intimately connected with their distance from the Sun, but in rather a peculiar fashion. Whereas a solid body reflecting sunlight (ignoring phase effects) will be four times as bright when twice as close to the Sun (following an r^{-2} law), comets in general are 16 to 64 times as bright when twice as close to the Sun (following laws from

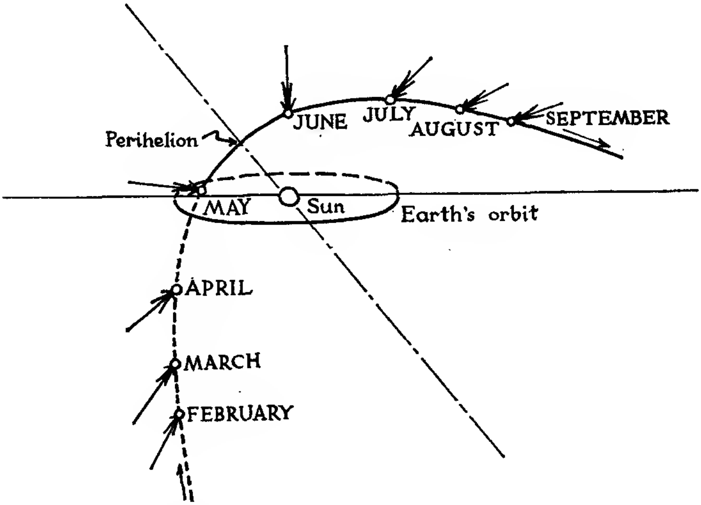

Fig. 2. The orbit of Comet Tago-Honda-Yamamoto, 1968a. The position of the comet is shown on the first of every month. Note how the comet tail is streaming behind the head in February and March, moving sideways in May, and preceding the head in August and September.

r^{-4} to r^{-6}). In extreme cases, this can be even more. Periodic Comet Honda-Mrkos-Pajdusaková, an extremely diffuse comet with a poorly defined nucleus, follows a law that is usually as high as r^{-10}, making the comet 1,000 times as bright when twice as close to the Sun. So strongly is this comet's brightness dependant on its distance from the Sun that it has never been observed farther than 1·2 AU from the Sun, or more than 2 months from perihelion, despite the fact that it can be as bright as magnitude 9 at perihelion ($r = 0{\cdot}56$ AU).

It is clear, then, that comets are more than collections of dark material reflecting sunlight, and the spectroscope quickly provides the answer here. The head of an active comet is rich in neutral, un-ionized gas molecules, excited by fluorescence in the same way as in domestic strip lighting.

As the comet moves sunwards, the intensity of the solar wind increases, and gas and dust are released from the nucleus as it warms. The gas becomes ionized by the ultra-violet light in the solar wind as it leaves the head and moves down the tail. The phases in the life of a comet can be outlined as in Figure 3.

The comet is discovered at a great distance from the Sun as a large diffuse patch (a) with no central condensation or apparent nucleus. In fact the nucleus is there, but it is so faint and inactive a body as to be undetectable. After some time, when the comet approaches closer to the Sun, the coma shrinks somewhat and the increasing strength of the solar wind strips off its outer layers. A central condensation begins as the nucleus warms from its glacial coldness, and begins to release dust and gas (b). Soon a strong central condensation develops and a faint nucleus becomes visible (c). A faint gas tail begins to appear (d) and this rapidly strengthens into several streamers (e). For comets approaching closer to the Sun than the distance of the Earth's orbit (1 AU), this tail can expand to a sheaf of streamers which diverge from the nucleus (f). Quantities of dust are now being emitted, and this spreads in the plane of the comet's orbit. Comets going closer than about 0·3 AU eventually produce such volumes of gas and dust on the sunward side of the nucleus that the overlying layers protect freshly ejected material, and this can expand sunwards for some time before being swept away from the Sun by the now strong solar wind. The overall effect now becomes like a hollow cylinder (g), producing a bifurcated appearance. On rare occasions, comets go as close as 0·01 AU to the Sun, and such sungrazers are then so close that material is stripped away with incredible force by the fierce solar wind (h).

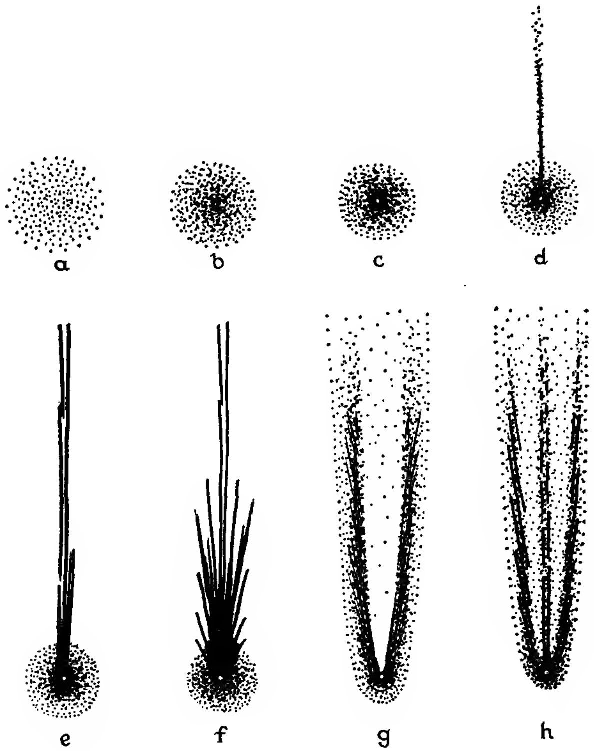

Fig. 3 (a) *to* (h). *The course of development of an active comet as it approaches the Sun.*

As the comet moves away from the Sun, the whole series of changes is repeated in reverse, except that tails are generally broader and more diffuse than when the comet was at the same distance and approaching. Comets which always stay at large distances never develop beyond stages (a) or (b), whilst comets with perihelion near the Earth's orbit may reach stage (e) or (f). This is all very general, in any case, and each comet has its own special characteristics.

The comæ of comets seem to show a relation between their size and their distance from the Sun, decreasing in diameter as they move sunwards. Thus Comet Encke has a coma diameter of 500,000 km at 1·5 AU, 130,000 km at 1·0 AU, 20,000 km at 0·5 AU, and only 5,000 km at perihelion (0·34 AU). The increase in the intensity of the solar wind has a strong effect on the extremely tenuous coma, which contains only about 100,000 molecules/cu.cm. (rarer than the finest vacuum obtainable on earth!). Since the tail contains only about 100 molecules/cu.cm., it is clear that the nucleus is the only substantial part of the comet. Much work has now been done on elucidating the actual nature of the nucleus.

In large telescopes the cometary nucleus appears either stellar or as a tiny disk. It is normally faint and makes up only from 0·1 to 10 per cent of the total light of the comet. Its spectrum consists almost entirely of scattered and reflected sunlight, with little or no gaseous emission lines. Some sort of solid body or bodies seem to be involved, and taking a reasonable value for the reflectivity of these (say 10 per cent), estimates of the diameter of the nucleus are then possible. These vary from 1 to 500 km, but cluster around 40 to 80 km. Taking a mean value of about 60 km, and the average mass of a comet of about 10^{19} gm, the density of the nucleus works out at 1/10th gm/cc. – too light to be a solid rocky or metallic body. (As we have seen, the coma and tail make so little contribution to the mass of the comet that they can be safely ignored here.)

The nucleus is therefore a relatively light affair, consisting of either a fairly loose conglomerate or a collection of individual particles held together by their gravitational attraction. This latter explanation was held for a long time, supported by observations of the dust tail, and of course, observations of meteor streams. The connection between comets and meteor streams can now be regarded as established. Most of the really active meteor streams individually have orbits which correspond quite closely with one of the known comets. Thus the Perseid meteor shower is derived from Comet Swift-Tuttle 1862 III, the Leonids from Comet Tempel-Tuttle 1866 I, the Lyrids from Comet Thatcher 1861 I, and the Draconids from Comet Giacobini-Zinner 1946 V. In the latter case, the meteor and comet orbits are identical, and slight differences in the other cases can be explained by planetary perturbations and other dispersive effects. These meteor showers consist of solid particles which can be up to many grams in weight, and so it becomes clear that as well as losing fine dust, comets also scatter considerable quantities of more substantial particles as they become active. These particles leave the head of the comet at very low velocities, and in quite a short time become scattered all round the comet orbit to produce the meteor stream. The meteor particles are too heavy to be swept away by the solar wind in the manner of the dust in the tail; but on the other hand, they contain no really large lumps big enough to produce a meteorite. Thus there is no recorded fall of a meteorite belonging to a cometary meteor stream.

Could the comet then be composed of a swarm of such meteor particles and dust, becoming denser towards the centre, and held together by their mutual gravitational attractions? This 'flying gravel bank' model was very attractive, and went a long way to explaining most cometary phenomena. Unfortunately, it also meets considerable difficulties.

Comets clearly contain considerable amounts of gas. This produces the coma and gas tail, and estimates suggest that 1/10 per cent of the mass of the comet is gas. This must be adsorbed on to the surface of the particles, for frozen gas in such a loose collection of material suggested by the flying gravel bank model would be unstable. However, to adsorb this amount of gas would require particles only a few microns in diameter (the amount of gas a particle adsorbs is proportional to its surface area; for clouds of a given mass, those consisting of smaller particles will adsorb more gas, since they have a larger surface area). But this size is in the range where solar interactions strongly influence the particles' motion, whisking them away down the tail. So our meteor particle cloud consists of particles which are too large to adsorb the required amount of gas.

Furthermore, a swarm of independant particles could not survive gravitational disturbances. We have already seen how rapidly meteor particles become scattered round the comet orbit. If the comet were a loose cloud, then it should become gradually elongated with time, as the particles drift and spread along the orbit. Yet comet nuclei are always recorded as sharp point-like objects. Comet Encke has made more than fifty recorded returns in its elliptical orbit, and Comet Halley has been recorded for over 2,000 years; yet both these comets still retain star-like nuclei. Something more substantial than a loose cloud is clearly indicated.

The clinching argument comes from the study of a group of sun-grazing comets known as the Kreutz group. These comets all move in very similar orbits that go so close to the Sun that the comet actually passes through the solar corona. The Great Comets 1882, and Ikeya-Seki 1965f, both belong to this group, and were extensively studied. Near perihelion, the nuclei of these comets were seen to split into several distinct fragments. This implies that blocks of material of many metres, perhaps kilometres diameter, must be involved to withstand the withering blast of energy, and the tidal disruptions at perihelion. The 'flying gravel bank' model cannot explain this splitting into distinct fragments, and a comet of this type would completely disintegrate at the perihelion distance of the Kreutz group.

These results suggest that although the nucleus is not solid in the planetary sense, it must certainly possess considerable structural cohesion. It was on this basis that Whipple proposed his 'icy-conglomerate' model for cometary nuclei. This has been rather misleadingly called the 'dirty snowball' model, but the amount of frozen gases is quite small, and it is more likely that the nucleus actually resembles a mass of frozen soil, with larger lumps up to metres or even kilometres towards the centre. This model quite satisfactorily explains all the phenomena described above, and can be visualized as follows.

The surface of the ball of material crumbles readily, and dust particles become dislodged. Removal of surface material reveals lower levels still rich in frozen and adsorbed gases. This vaporizes under solar influences, and the expanding gases gently push away the already dislodged material. A crack may appear in the surface of the nucleus, allowing gas to flow from the fissure with greater force, perhaps dislodging larger pieces of solid material. If a degassed section of the surface hardens under the solar glare to a solid crust, then a considerable pressure could build up as the gas-rich interior warms. Eventually the surface will yield, and a large amount of gas and dust is suddenly released. This gives an excellent mechanism to explain cometary outbursts.

Comets frequently undergo sudden increases in brightness, which are usually accompanied by the release of large amounts of gas and dust. Figure 4 shows sudden flare-ups (arrowed) in the magnitudes of three recent comets. The outburst of Comet Alcock, 1963b, involved a ten-fold increase in light output in less than 6 hours. Comets normally flare near perihelion, and most flares occur during periods of high solar activity. Some particularly active comets, however, show flares at great distances. Comet Humason, 1961e, showed repeated explosions during its three-year period of visibility, many occurring as far as 4 AU away from the Sun, where most comets are normally invisible. Even more active is Comet Schwassmann-Wachmann I, 1925 II, which has an almost planet-like circular orbit beyond the orbit of Jupiter. This normally 18th-magnitude object periodically undergoes violent explosions, showing as increases in light output. Thus Comet 1925 II suddenly brightened to 10th magnitude in 1959 October to 12th magnitude in 1960 January and 14th magnitude in 1965 January. Whilst the icy-conglomerate theory can explain these explosive incidents, the flying gravel bank model cannot.

As we have seen, comets approaching close to the Sun tend to break into several discrete pieces, and once again Whipple's theory can satisfactorally explain the facts. However, many comets have been observed to split into two in a quite leisurely fashion for no apparent reason, and in a completely unviolent way,

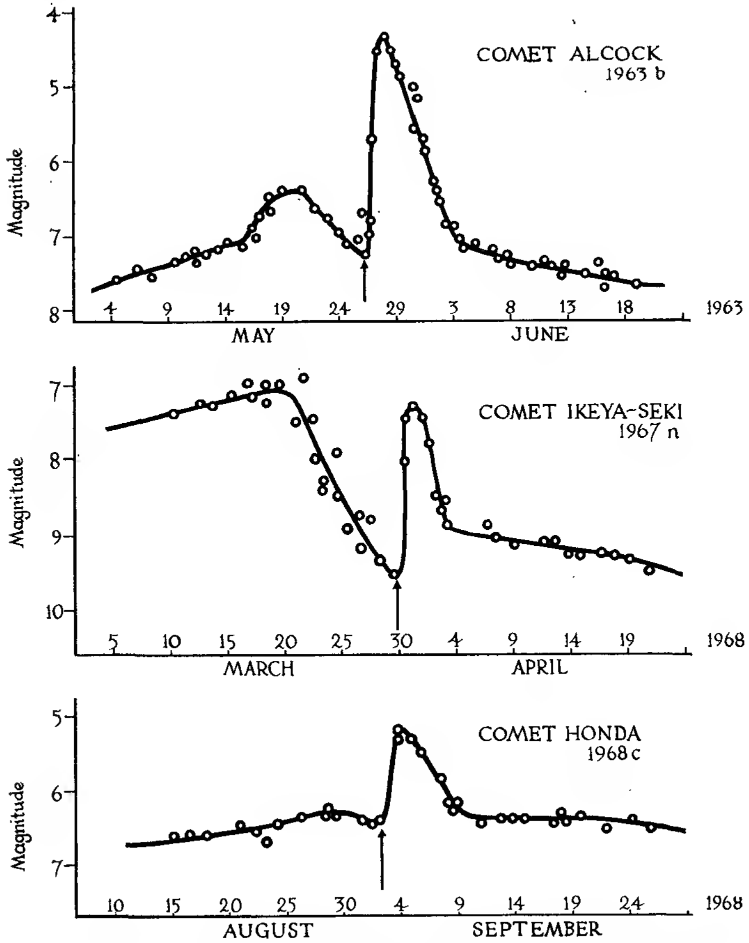

Fig. 4. Outbursts in the optical brightness of three recent comets. In all cases the outbursts occurred in just a few hours.

frequently at large distances from the Sun. Comet Biela is perhaps the most famous one here, a periodic comet that split into two fragments in January 1846. The two independent comets moved slowly apart, and at their next return, in 1852, appeared as a principal object with a smaller identically shaped comet close by. In more recent times, Comet Wirtanen, 1957 VI, split quietly into two in January 1957, and the two comets, separating slowly at a rate of only 1½ metres/sec, were followed for three years as they faded.

How can this sort of disintegration be explained? On the Whipple model, cometary disruption (outbursts apart) is not in general a violent process. Surface layers slowly evaporate off and disperse. Gradually, perhaps a crevasse appears in the nucleus, and it enlarges slowly as the ices evaporate until it almost cuts the nucleus in half. Finally, the small connecting bridge evaporates, and the two halves become independent comets gently pushed apart by their evaporating gases. The break-up of comet nuclei in this manner may be a much more common phenomenon than is generally realized. Photographs of comets using modern cameras and films has revealed that quite a high percentage of new comets show multiple nuclei at some time or another. In 1968, incidentally a year close to solar maximum, Comet Whitaker-Thomas, 1968b, developed a double nucleus at the end of June, and Comet Honda, 1968c, showed a split nucleus at the end of September.

It can be gathered from all this that comets are rather fragile objects, and cannot have long lifetimes on the astronomical timescale. Recent work has confirmed this abundantly.

The 'absolute' magnitude of a comet is defined as the magnitude it would have if situated one astronomical unit from both the Earth and the Sun. Comets rarely place themselves in such a convenient position, but by observing the brightness of a comet along a fairly lengthy section of its orbit, one can accurately estimate a comet's absolute magnitude mathematically. Figure 5 shows estimates of these absolute magnitudes for three periodic comets at each return during their past history. It can be seen that all three comets show an accelerating fading in absolute magnitude. Comet Wolf shows quite an incredible decline in brightness, and even Comet Encke, although much more constant, shows a steady decline. On these results, then, the lifetimes of

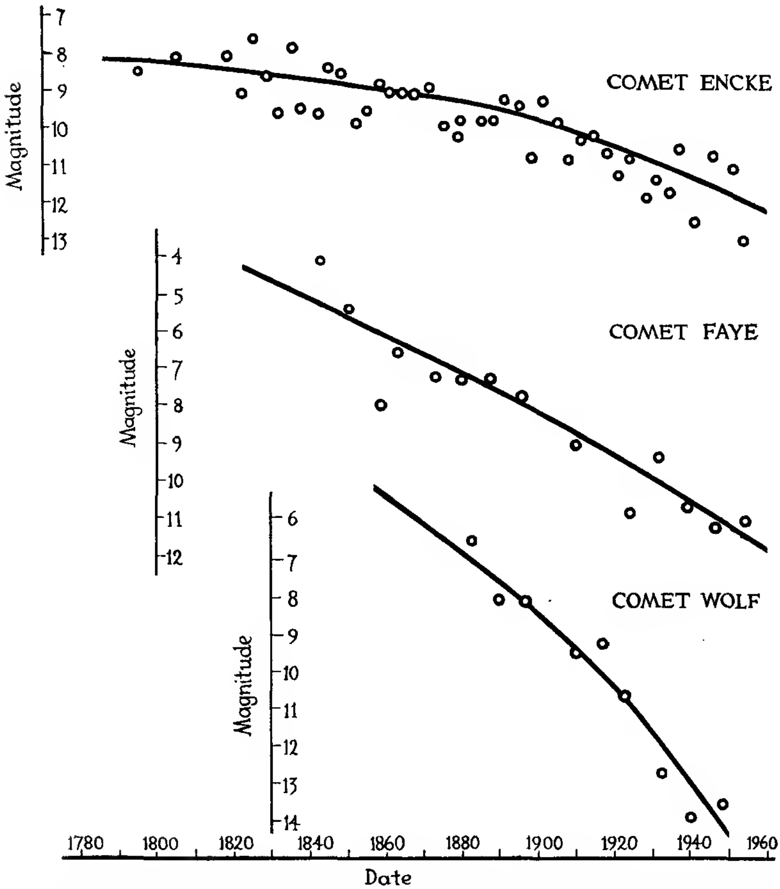

Fig. 5. Estimates of the absolute magnitudes at each return of three periodic comets are plotted here. Comet Encke seems to be a remarkably stable object, since most periodic comets fade as quickly as Faye or Wolf.

comets in such short period orbits must be reckoned in centuries only.

One interesting observation is that whereas new comets are very rich in dust as well as gas, older comets are rich in gas with a remarkable dearth of dust. This might at first sight be the opposite of the expected result – should not old comets become 'de-gassed' and inert? It must be remembered, however, that on the Whipple model, frozen and particularly adsorbed gases will be found at all levels. On the other hand, because of the slow way in which the nucleus condensed initially, the larger blocks of solid material will be near the centre, with the chips and dust in the outer layers. Hence, as the comet loses its outer layers, the material lost becomes larger in size, until relatively little dust is left. Gas, however, still continues to evaporate off. This also explains why no meteorites have fallen from a cometary meteor stream. The large lumps of material are locked away in the centre of the nucleus, and any large lumps set free will be held gravitationally, whereas light dust is blown away. It seems that comets could be much stonier in the central part of the nucleus than has hitherto been supposed. By the time that the comet has lost enough material to expose large pieces of matter, and the mass of the nucleus has fallen to a value allowing such lumps to escape, the comet, as we have seen, will have probably faded so much as to be effectively invisible as a cometary object.

This final fading is probably punctuated by brief outbursts – the death-throes of the comet. Comet Wilson-Harrington was a periodic comet discovered as a faint diffuse object in 1949. Its period was 2·3 years, nearly two-thirds that of Comet Encke, but the comet has not been seen since. This was probably a comet that had reached the last stages of decay (because of its short-period orbit), giving one of its final outbursts. Periodic Comets De Vico-Swift and Holmes are two comets that were both observed as quite bright objects just visible to the naked eye on two occasions each during the last century. After that they were lost, but recent accurate computations of their orbits has led to their recovery, as very faint 18–20th magnitude objects. Clearly their earlier 'bright' appearances were similar prolonged outbursts of rapidly fading periodic comets.

What is the ultimate fate of defunct comet nuclei? If the central part of the nucleus consists of a collection of large chunks of rock, then the comet could fade to produce an inactive asteroid-like object, shining purely by reflected sunlight. As has already been mentioned, there is no sharp dividing line between small comets with little or no coma, and asteroids travelling in the same type of orbit. Indeed, a system of asteroids known as the Apollo group exists, whose members move in very comet-like orbits, separated from the normal asteroid population. Could these be the residues of long decayed periodic comets? Periodic Comet Arend-Rigaux was discovered as a small diffuse object in 1950, but appeared completely stellar in its 1957 and 1964 returns. Had it been discovered in either of these two latter years, we can only conclude that it would have been classified as an asteroid moving in an interesting cometary orbit. The same applies to Periodic Comet Neujmin, an object that only gave a cometary appearance at the time it was discovered. One should be careful here, though, since it is not being proposed that *all* asteroids are dead comets. The Apollo group is quite a small group, but large enough to contribute significantly to the flux of meteorites in the region of the Earth, and leading to the distinct possibility of true *cometary* meteorites.

One intriguing possibility concerns the two satellites of Mars, Phobos, and Deimos. Recent work has shown that the orbits of these satellites have evolved from highly elongated ones, making it probable that these 'moons' are in fact captured asteroids of the Apollo type. There thus seems to be a possibility that Phobos and Deimos are the remains of two large ancient comets.

No article on comets would be complete without a few words about the origin of these fascinating objects – a subject that is still, lamentably, one for speculation. There are certainly few enough facts to go on. One of these is that essentially all the new comets that are visiting the central part of the Solar System for the first time, move in orbits that are very elongated ellipses.

This implies that comets are residents of the Solar System, and do not enter it from outside. These ellipses all have most distant points (aphelia) just inside the sphere of gravitational influence of the Sun, and this has led several astronomers to speculate that a large cloud of deep-frozen comets exists, circling at the periphery of the Solar System. Perturbations by passing stars may lead to comets having their circular orbits changed to long ellipses, to produce the active comets visible as they pass perihelion. Calculations suggest that a million million (10^{12}) comets must exist there to account for the numbers that we see in the vicinity of the Sun.

But how did the comet cloud form? It is probable that it condensed from material situated at the edge of the dust and gas cloud from which the Solar System itself formed. A second, less satisfactory theory suggests that the comet cloud is condensed from material that the Sun has 'swept-up' as it moves round its orbit in the galaxy. All theories are, unfortunately, at the moment pure speculation.

Comets, then, are certainly remarkable objects. Born on the outskirts of the Solar System, they must represent the most fragile bodies in the Sun's family. This fact alone should indicate their great potential as indicators of solar activity. Of those deflected from their orbits on the fringes of the Solar System, it is now known that at least half acquire enough energy to leave the Solar System entirely, to begin wandering about the Galaxy from star to star. The majority sweep round the Sun to recede into the depths of space for an æon or two, although some, certainly, are roughly handled by close approaches to the Sun. The unlucky few make close approaches to the major planets, and have their orbits altered into short period ones. In such paths, these fragile collections of boulders, dust, and ices must count their lifetimes in centuries rather than the thousands of millions of years appropriate to the more substantial members of the Solar System.

Exploding Stars

R. C. MADDISON

Some of the earliest theories of the structure of the universe were concerned with ideas of 'perfection', in the geometrical sense, and each of the planets and stars was supposed to be fixed to its own particular gigantic crystal sphere which revolved slowly around the hub of the universe. Change was associated with imperfection, and the whole neighbourhood of the Earth was therefore regarded as highly imperfect. The stars, on the other hand, were seen as eternal and changeless and fixed on to the outermost crystal sphere that marked the boundary of the universe.

The notion that the stars are fixed and changeless is unacceptable to us because we have a knowledge of the basic laws of physics describing forces and motions and energy, and because generations of astronomers, using sophisticated instruments and techniques, have been able to measure the motions and distances of the stars with a fair degree of accuracy. The observers of antiquity faithfully recorded their observations within the limits of accuracy of their techniques, and interpreted them in the light of their beliefs. The astounding thing about these men and their observations is that they must have seen shooting stars, comets, and eclipses, and rightly, of course, regarded them as local phenomena like the planetary motions, while at the same time, they must also have seen variable stars like the 'Demon' Algol regularly changing in appearance in what they regarded as a changeless environment. This inconsistency cannot be attributed to a lack of precision in those early days, but it is significant that, throughout the whole period during which these ideas of stellar perfection were propounded, no-one seems to have seen any more obvious or unmistakable changes in the appearance of the sky.

The sudden outburst of a very bright star, where apparently there had never been a star before, is something that the shepherds and astronomers of those days would certainly not have missed, and careful records would have been kept. The fact that such records do not appear to exist, and the prevalence of notions of perfection at this period seems to imply that any outbursts like this, if they happen at all, are exceedingly rare events.

A highly authentic record of an unmistakable addition to the night sky was Tycho Brahe's observation of November 1572. 'One night,' he writes, 'as I was examining as usual the celestial vault, the aspect of which is so familiar to me, I saw, with unspeakable astonishment near the zenith, in Cassiopeia, a star of extraordinary brightness. Struck with surprise, I could scarcely believe my eyes. To convince myself that there was no illusion, and to obtain the testimony of other persons, I called the workmen occupied in my laboratory, and I asked them, as well as all the passers-by, if they saw, as I did, the star which had so suddenly made its appearance. I learnt later that, in Germany, the coach drivers and others of the people had acquainted the astronomers of a strange appearance in the sky, and thereby furnished the occasion for a renewal of the accustomed railing against scientific men.'

Tycho's star was obviously a very exceptional one that was easily recognized even by those who were not familiar with the patterns of the constellations. We are told that this star 'could only be compared to Venus at quadrature', and that 'it remained visible in the day at noon if the sky was clear'.

Several less spectacular outbursts have been recorded in the pages of history, but only two others seem to have approached the magnificence of Tycho's star. These were the 'guest star' of July 4, 1054, which was mentioned in Chinese and Japanese documents of the period, and Kepler's star of 1604, which was apparently remarkable for its vivid scintillation. Recent cases of the discovery of the less spectacular, but most interesting, outbursts are Nova Delphini, 1967, and Nova Vulpeculæ, 1968. Both of these were discovered by George Alcock, and were the result of a deliberate search. In the case of Nova Delphini, Mr Alcock recounts how on that particular evening, even before he had adjusted his binoculars, he had a premonition that something of importance was about to happen. It was only a matter of minutes before he had seen and recognized this 'new star' at magnitude 5·6 just north of the parallelogram in the constellation Delphinus. This was no mean achievement when one remembers that this part of the sky is particularly rich in fairly bright stars. The discovery, after more than 12 years of patient searching, must have been a rich reward for this meticulous observer, who already had several comets to his credit. The second discovery was made less than 10 months after the first, when the 5·6 magnitude stranger was immediately recognized for what it was. This time the observation was made in the early hours of the morning and the sky had become too bright for observation before any independent check could be made. As soon as darkness fell on the following evening the new star was seen to be more than half a magnitude brighter than on the previous night. These faint and temporary additions to the night sky are much more frequent than the exceptional outbursts seen by Tycho and Kepler, and the difference is thought to reflect some basically different process rather than an effect of perspective. The very bright ones are called 'supernovæ' and the others are called 'novæ', but these names are very misleading in the sense that the phenomena are certainly not new stars. If anything, these outbursts are more characteristic of older stars than younger ones, and they probably represent a phase in the life-cycle of a star that has been in existence for a very long time.

Measurements made during the last few years on the nature of our whole galaxy of stars have shown that between 25 and 30 stars suffer outbursts and become novæ every year. This figure, however, is estimated for the whole of the Galaxy from observations that can be made in only a very restricted part of it. When one remembers that there are about one hundred thousand million stars in our Galaxy, and that most of these are hidden from view behind clouds of absorbing material, the problems of searching for and observing novæ seem very real. Many astronomers are waiting patiently for the day when one of the spectacular supernovæ will erupt within the range of their spectroscopes, but they are so very rare that one is more likely to come up with a big win on a premium bond. Some supernovæ have been detected in other galaxies during the last few decades, but they have been much too remote for detailed study.

The major difficulty in observing these strange stars is that the explosive increase in brightness is so rapid that, by the time it has been detected and equipment trained on it, the most interesting part of the event is over.

These stars are not called exploding stars without good reason. The novæ may show an increase in brightness of more than 60,000-fold in a period of hours or a few days; this corresponds to an increase in magnitude of 12, and implies a final absolute magnitude of about $-7{\cdot}5$. By contrast the supernovæ, which seem to come in two distinct ranges, may increase in luminosity ten million fold for type II and as much as a hundred million fold for type I.

Within the framework of this broad classification of exploding stars it is perhaps not surprising that no two novæ seem to have the same type of light curve. Although all of them undergo a rapid increase in brightness which is followed by a more gentle fall-off in intensity to the original level, the detailed shapes of the curves vary considerably. The peak brightness is usually attained after a few days and, since it is the subsequent behaviour of the star that varies most, it is this that is used in the more detailed classification. The group known as the 'fast novæ' seem to complete the whole cycle of activity in a matter of weeks, whereas the 'slow novæ' may stay at maximum brilliance for some months before fading to their original brightness. There are, of course, novæ that defy this simple form of classification; a notable example of this type is Nova Delphini, mentioned earlier. In this case the initial rise in brightness was preserved for many months and there were several subsequent maxima, the greatest of which took place almost six months after the initial outburst.

Some of the most interesting measurements of these exploding stars are made by hindsight as soon as the position of the star has been accurately established. Many observatories throughout the world are engaged in regular survey and patrol photography, so that an almost continuous record is kept of the appearance of the entire sky. Obviously, the task of examining these photographs in detail is a formidable one, but it is usually possible to detect small changes between consecutive photographs very quickly, and speed is of utmost importance. This is done using a device called a 'blink comparator', which permits the operator to view two pictures alternately in rapid succession. If the two views have been taken with the same camera, and the images are lined up correctly, then the operator will see no difference between the views unless some change has taken place in the interval between taking the pictures. If, for example, a nova has appeared or an asteroid has changed its position relative to the background stars, then the difference will be seen as a 'blink' as the images are seen in succession through the comparator. Many novæ have been detected by this method, but many of the thousands of stellar images that appear on these survey plates may well be potential novæ yet to explode and probably to be identified in retrospect after the event. Once a nova has been seen, and its position measured, then the earlier survey plates may be sought out and examined, and the pre-nova stages of the star determined. In this way it is possible to identify the pre-nova spectral type and magnitude, and to show whether any previous variability had occurred.

One of the important results that has come out of this type of retro-observation has been the determination of the relationship between spectral type and nova tendency. Nearly all the stars that have been studied in their pre-nova stages have been found to be of types B or A, and they have all shown irregular variability in this stage. Detailed study of the spectra has shown that these nova-prone stars lie somewhere between the main sequence and the white dwarfs on the Hertzsprung-Russell diagram; this indicates that they are very probably old stars in a state where they are using the last remnants of their nuclear fuels, and where the reacting zones may be relatively close to the stellar surfaces.

The pre-nova and post-nova stars are found to be almost identical in magnitude and spectral characteristics. An obvious difference, however, must be in the total energy content, since it has been shown that, during the explosion, the energy equivalent of between one-hundredth and one-thousandth of the star's mass is radiated away. Many of the post-nova stars shine on as if nothing had happened, and it is very difficult to recognize a star that may once have been a nova. Fortunately some novæ are recurrent, and have been through the experience more than once. A close watch is kept on these in the hope that they will erupt again so that the outbursts can be followed through from the beginning. Recurrent novæ seem to be less violent than the ordinary novæ, and may brighten by only 7 or 8 magnitudes instead of the usual 10 to 12 magnitudes; there is a strong temptation to treat them as long period variables, where the period might be related to the size of the outburst. The six recorded recurrent novæ are (1) RS Ophiuchi with outbursts in 1898 and 1933, (2) T Pyxidis with outbursts in 1890, 1902, 1920, and 1945, (3) N Sagittarii with outbursts in 1901 and 1919, (4) T Coronæ Borealis with outbursts in 1866 and 1946, (5) U Scorpii with outbursts in 1863, 1906, and 1936, and (6) N Sagittæ with outbursts in 1913 and 1946.

One might begin a brightness classification, for instance, with the U Geminorum-type irregular variables, which brighten by 3 or 4 magnitudes every few weeks and which are usually called dwarf novæ. These might be followed by the recurrent novæ, changing every few years by 7 or 8 magnitudes. Then would come the single novæ, which reach magnitudes 10 or 12 above their 'ground states' and which might recur after very long periods, and the list would end with the supernovæ that increase in brightness by between 18 or 20 magnitudes and are never quite the same again. Clearly there might be some underlying physical reason why the periods of these unstable stars seem to be related to the size of the outburst. It is almost as if the stars require a recovery period that is proportional to the activity they undergo, but the reasons why some stars become novæ and others do not are far from being understood at present.

In order to find out what is happening during a nova outburst, we must be able to examine spectra of the event taken at various phases of the active period, and we must bear in mind the various factors that affect the positions and intensities of the spectral features under different conditions. We must remember that hot high-pressure gases and incandescent materials give rise to spectra of a continuous nature showing no bright or dark lines. If a sphere of such hot material is surrounded by an envelope of cooler gases, then discrete amounts of energy are subtracted from the underlying continuous spectrum by the cooler material, and this process gives rise to dark absorption lines in the spectrum. If we detect light that is produced by heated and excited low-pressure gases, then we see energy that is radiated at fixed colours that are determined by the nature and physical state of the elements present. This process leads to bright line emission in the spectrum, and we can estimate the temperature and excitation condition of the hot gas envelope.

The chemical constituents of the material being studied determine the positions of the bright and dark lines in the spectrum, but the positions can be affected by outside factors. By far the most important of these factors is the velocity of the source being studied relative to the observer; this effect is known as the Doppler effect. A hot gas will normally send out light as a series of rays of differing colours or wavelengths. For each distinct colour a certain number of light waves will be emitted every second towards the observer. If, however, the source of light is moving towards the observer at a certain speed, then he will intercept more waves per second than the source is sending out per second, and he will see this as a change of colour – in this case the light will have become bluer. The opposite effect occurs if the source is moving away from the observer – and in this case the shift in colour is towards the red.

Spectra obtained from most novæ seem to have certain well-defined characteristics in common. During the initial phase of the outburst, when the brightness is rapidly increasing, the spectrum is continuous but crossed by narrow absorption lines. These lines are generally shifted towards the blue end of the spectrum by amounts which imply velocities of approach ranging from a few hundred to more than a thousand miles per second; this must represent the initial explosive phase, when the star begins the violent expansion that is responsible for the observed increase in brightness. This stage is followed by the addition of broad emission lines that seem to be unshifted in wavelength. These emission lines appear broadened because some of the material causing them is receding, while, at the same time, other parts of the material are approaching. The picture that emerges is one of a shell of highly excited low-pressure gas that must be expanding away from the central star. The part of the shell that is approaching gives rise to the blue shifted parts of the bright lines, and the far side of the shell, which we see through the intervening material, gives rise to the red-shifted component of the bright lines.

Close examination of the spectra reveals that these broad emission lines still have narrow absorption lines on their blueward sides. These are caused by the shell of cooler material, outside the hot shell, which was the first material to be thrown out when the explosion began, and which has the greatest approach velocity. This is what we would expect to find if the nova behaved like a gigantic explosion, because the first material to be ejected would have experienced the greatest accelerating force and would be moving fastest. As the explosion progresses, so the explosive force would be diminished, and the subsequent material to be ejected would be moving slower. The final stages of the outburst, when the nova has lost much of its brilliance, are characterized by the fading of the original emission lines, and the appearance of broad lines that are usually only seen in the spectra of gaseous nebulæ. These indicate that the shell has expanded sufficiently to become diffuse, so that the normally ‘forbidden’ lines of very low-pressure gases begin to appear.

On several occasions the expanding gas shell around a nova has been photographed directly, using very large telescopes; in the case of Nova Persei, 1901, the shell was studied over more than 50 years as it gradually spread away from the central star. This sort of measurement is useful in a secondary way because a combination of the radial velocity, as measured by the blue shift, and the rate at which the image size increases is an indication of the distance of the nova and therefore of its absolute magnitude.

The best-known example of an expanding shell following a nova outburst must be the 'Crab Nebula' in the constellation Taurus. This object has been known for many years as a prominent misty patch which occupies the position at the top of Messier's catalogue of interesting objects. Spectrographic measures show that it is a mass of gas that is expanding at about 700 miles per second. Long-exposure photographs show that the image is made of turbulent filaments of gas and dust, but it is not possible to identify anything that may have been the central star. In this case the nebula seems to be much bigger and more disturbed than the shell of gas sent out by a normal nova, and it is thought to be the remains of the supernova of 1054. If one works the present rate of expansion backwards in time, one can arrive at an estimate of when the explosion occurred, and there is substantial agreement between the estimate and the Chinese records of the event. An interesting feature of the Crab, and many other similar objects that have since been discovered, is that it is one of the strongest sources of radio waves in the entire sky. The turbulent motions of the electrons and ionized material of the expanding filaments generates strong magnetic fields and electric currents, and these conditions give rise to radiation which is characteristic of accelerated charges and which is called 'synchrotron' radiation. It may be that supernova remnants are the constituents of the peculiar objects known as 'pulsars' – the strangely regular radio sources that could be evidence for the existence of neutron stars. One of these certainly seems to lie near the centre of the Crab, but there are still several strong radio sources of this kind that have not been identified with any optical object.

Unfortunately there are still no observations of supernova-prone stars, and it seems likely that there never will be. It looks as if our understanding of these things will have to depend on optical and radio measurements made after the event; and although this gives us a fair picture of what happens when a star becomes a supernova, the underlying reasons why it happens are still very obscure.

The theoretical description of what the interior of a star is like, and what nuclear reactions and processes take place there, is very much an educated guess, but the evidence is that certain types of stars at certain stages in their lifetimes become unstable, and throw off large quantities of material. This may be precipitated when the equilibrium between gravitational forces and the pressures of gas and radiation becomes disturbed. Such conditions may arise when the reacting core of a star has become a shell much nearer the surface than the centre of the star. The central parts may find themselves without any means of support from nuclear reactions, and the gravitational forces may dominate and eventually cause the catastrophic collapse of the whole star. Whether this is the case or not, the events are obviously spectacular, and they will be watched for endlessly and studied in great detail. We should perhaps draw some comfort from the fact that all these unstable and explosive stars seem to be old stars of types B or A, while our Sun continues unperturbed as a middle-aged G2.

Cosmology—The Debate Continues

KEITH B. HINDLEY

Ever since Man evolved enough intelligence to provide himself with leisure time, he has regarded the universe with awe and curiosity. Men of all ages have sought to produce ideas of the universe which satisfactorily explain all the phenomena they have encountered. Initially, of course, with so much inexplicable, divine interference – an agent requiring no explanation, was invoked to provide theories. As science developed, however, this has been superseded by more concrete proposals involving rather more scientifically acceptable facts.

The earliest ideas of the universe involved a flat earth, with the sky as a hemispherical dome on which the stars were painted. The Sun, Moon, and planets were the abodes of divine beings, moving in front of the stars. The Greeks came to the conclusion that the Earth was curved, leading to the proposal that it was a 'ball'. The scientists of the day were able to measure the diameter of the globe with surprising accuracy. Suggestions that the Sun was not a god, but a ball of blazing metal, and that it, rather than the Earth, was the centre of the universe, were treated as heresy. Such revolutionary ideas had to wait for acceptance by another age. The ball-like Earth with the Sun, Moon, and planets moving round it at the centre of the fixed star sphere, were ideas that persisted through the Dark Ages up to the Renaissance in Europe.

Then, with evidence piling up, particularly after the invention of the telescope, the Sun was at last consigned to its rightful place at the centre of the Solar System. Irregularities in the timings of the eclipses of Jupiter's satellites led Ole Rømer to discover that light did not move from place to place instantaneously, but with a finite velocity of some 186,000 miles per second.

Newton proposed a theory of gravitation to explain the motions of the planets, but the view of the universe remained essentially unchanged. The Solar System was still at the centre of the dark sphere on which the stars hung. The stellar system was still essentially two-dimensional.

It took the genius of William Herschel to shatter this sphere once and for all. In a lifetime of brilliant researches, Herschel laid down the foundations of modern astronomy. He showed that the Sun was merely an ordinary star, moving through a collection of similar stars. The outline of this cluster of stars – nowadays called the Galaxy – was determined with some accuracy. Herschel rightly deduced that many of the nebulæ – hazy patches visible all over the sky – were in fact stellar systems just like our own seen across vast distances of space. Herschel also spent considerable time and effort trying to produce a theory to explain the evolution of star systems. So it can be truly said that Herschel added two dimensions to the universe, depth and time. Two things, however, prevented Herschel going any further; complete ignorance of the constitution of, and the distance of, a single star.

Advances were swift, however. Soon the distances of the nearest stars were measured, and several methods of distance measurement became available. Then the spectroscope was developed – an instrument capable of splitting up the light from an object into its individual wavelengths or colours. Each element has specific wavelengths of light which it absorbs. Consequently, when stellar spectra were found to be crossed with large numbers of dark lines, astronomers were able to deduce the constitution of the stars. These lines were useful in another sense. When a body emitting light is receding from the Earth, the light it emits is shifted towards the red end of the spectrum. If the body is approaching, the light is shifted bluewards. So the dark lines are no longer found at the expected wavelengths, but moved to the blue or red. This effect, known as the Doppler principle, allows astronomers to examine the spectrum of an object; the shift of the dark lines from their expected position is used to determine the velocity with which the object is approaching or receding. With these facts established, the foundations of modern cosmology had been laid.

In 1912, V. M. Slipher of the Lowell Observatory found that the Andromeda Galaxy – one of the closest of the nearby galaxies – was moving with a velocity of some 125 miles per second. By 1917, many galaxies had had their line-of-sight velocities measured, and nearly all of them were found to be receding. This was unlikely to have been due to chance, and the results caused considerable comment.

In the same year, Einstein published his theory of relativity. For centuries, scientists had argued about what to use as an absolute frame of reference; what body should velocities and distances be measured relative to? Einstein proposed that such an absolute frame of reference did not exist. He argued that all motion is relative, and one frame of reference is as good as another.

Einstein's General Theory of Relativity is a theory of gravitation intended to replace Newton's theory. It successfully explains several observed facts not covered by Newton's theory, including the bending of starlight as it passes close to the Sun's surface, and the swivelling-round of the axes of the planetary orbits.

In the same year, de Sitter investigated the theory of relativity and found that it had far reaching implications as far as cosmology was concerned. One result suggested that the universe could be in the process of expansion. Interest was switched back to Slipher's observations, and the motions of distant galaxies were reinvestigated.

Using the 100-inch telescope at Mount Wilson, Hubble made a survey, published in 1928, which showed that the fainter the galaxy, and presumably the farther away it was, the faster was it receding from the Earth. The Big-Bang theory of the universe was born. Here the whole of the matter of the universe is postulated to have been in a very dense, high-temperature ball in the past. This exploded, and the current observations showing the expansion of the universe are direct consequences of this.

Theoreticians quickly began to investigate the many possible variations of this theory. A large number of models were possible, depending on the nature of the expansion. As the galaxies are expanding away from each other, they are exerting their normal gravitational attractions. It clearly depends on the force of the initial explosion as to whether the expansion is fast enough to counter the attractions. So the universe could either continue to expand at an ever decreasing rate forever, expand so that the expansion ceases after an infinite time, or expand to a standstill after a finite time, coming to rest before commencing to contract at an accelerating pace. The second of these is almost academic, and seemed so unlikely that it could be safely eliminated. Observations could not distinguish between the other two, however.

One concept that all the relativistic big-bang theories share is termed *The Cosmological Principle*. This states that at any given time, all observers in the universe see the same general picture. In other words, all observers will note the effect of all other galaxies receding from them, and the overall density of the universe will be the same no matter where they are. At a different time, all observers will again have identical views, but different from the first example. One may point out now that an observer near the edge of the universe would see quite a different picture from one near the centre. Certainly relativistic universes have a finite volume which increases with time. However, these universes have no edge, since the cosmological principle forbids one. This involves the concept of *Curved Space* – an idea of a rather abstract nature. Since it is outside our normal experience, nobody, even the astronomers who deal with it every day, can actually visualize it. One must just learn to accept it. An analogy will serve to illustrate what is meant here.

This involves a flightless beetle, Albert by name, who lives on a perfectly smooth plane. Albert is a two-dimensional creature by nature, and although quite incapable of considering up or down (he is limited in thinking and movement to the two dimensions of the plane), is in possession of remarkable intellectual capacities. Actually, Albert is living on the perfectly smooth surface of a sphere the size of the Earth. As he moves about, Albert often ponders whether the apparently flat surface he lives on goes on for ever, or ends somewhere. The surface seems flat – for instance, the angles of a triangle drawn on the ground add up to 180°. But Albert is a curious beetle, and sets to drawing larger and larger triangles. To his amazement, he finds that the large triangles have angles that add up to more than 180°. The larger the triangle, the greater the excess. From this Albert correctly deduces that the surface on which he is living is curved. After due thought, he devises a theory that the surface may be a sphere. Here the surface has a finite area, but no edge, whereas a flat plane has either an infinite area if it goes on for ever, or a finite area if it has an edge. There is clearly a profound test of Albert's theory; he should be able to set out in a straight line and walk right round the globe, coming back to the point from which he started, from the opposite direction to which he set out.

He decides to put the theory to the test, makes a large black X on the ground, and sets off. The appearance of the plane does not change in the slightest as he journeys on, and it seems to go on forever. However, after a long time, he eventually arrives back at X from the opposite direction he set out, thus confirming his theory.

Albert therefore lives in a two-dimensional universe – a flat plane, with a finite area and no edge – a curved two-dimensional universe. The area of his universe need not stay constant; the sphere could be increasing in size rather like a balloon being slowly inflated. In that case, objects would be getting farther apart, and the area of the two-dimensional universe getting larger. But the cosmological principle would apply, all observers at any given time would still see the same picture, no matter where they stood. The density of objects would be the same, and the expansion would be identical everywhere.

Relativistic curved space is a direct analogy to Albert's two-dimensional curved plane, except that here we have three dimensions. The universe has a definite volume, but no edge, in the same way as Albert's plane had a definite area, but no edge. Our universe is expanding, thus increasing its volume, and the cosmological principle applies.

In the same way, in our universe, we should be able to set out at high speed on a long journey in a straight line, and after a finite time should arrive back where we started from, from the directly opposite direction. We are now at the stage where we may soon be able to detect the curvature of space, in the same position Albert was when he drew larger and larger triangles. Definite proof of the curvature of space would certainly be of great value.

By the end of the second world war there were many possible models of the universe using relativity; nearly all had a universe with curved space, finite volume, and beginning with a big-bang. Unfortunately, they all suffered from one great disadvantage–they predicted an age for the universe (6–8 thousand million years) which was very much less than the age of our own Galaxy estimated using reliable methods. This was clearly an untenable situation, but no escape could be found from the dilemma.

To get round this problem, in 1948 Bondi and Gold introduced a new type of cosmology, based on what is called the *Perfect Cosmological Principle*. In this theory, all observers in all positions in the universe, and *at all times* in the history of the system, see the same general picture. The universe expands, as observed, and in order to keep the density of the matter in the universe constant, it is postulated that matter is created continuously at a uniform rate just large enough to balance the decrease in density due to expansion. This is the so-called Steady-State theory of the universe, and since it states that the universe has an infinite age, it does not encounter the difficulty with the estimated age of the Galaxy that troubled the big-bang theory in 1948. Its advantages are several. The sheer simplicity of the perfect cosmological principle, and the absence of a singularity or big-bang were very attractive. Under the theory the universe has always existed and always will exist, in a state of uniform expansion. It does, however, involve to many an unjustifiable proposition, that matter is continuously being created out of apparently nothing. The rate of creation is small, amounting to 10 atoms appearing in the volume of the average living room every year. Although such creation is against one of the most fundamental laws of physics – the conservation of matter – many have argued that as such a rate of creation is undetectable at present, there is therefore no conflict. The theory states that the universe is infinite and not curved, and accepting the creation of matter, it is certainly a very simple, straightforward and elegant theory.

Initially it had no supporting theory of gravitation (the relativistic big-bang theories have Einstein's theory of general relativity), but this was eventually supplied by Hoyle and Narlikar. They took the equations of general relativity and modified them to take account of the continuous creation of matter. At the beginning of the 1950s, the steady-state theory held the pole position as far as credibility went.

The scene was very soon to be drastically altered. In 1952, Baade showed that the time scale of the relativistic models (actually based on the distance of the Andromeda Galaxy) should be multiplied by a factor of two. This brought the age of the Galaxy just within the time since the big-bang of the relativistic theories, and removed the very difficulty that gave birth to the steady-state theory. To this extent the steady-state theory lost its 'raison d'être'. But it had its staunch supporters by now, and attracted by its simplicity, these stuck firmly to their preference. The history of cosmology from this date has been concerned with attempting to indicate whether the observed universe best fits one or other of the big-bang or steady-state theories. At the moment we live in a very exciting time; cosmology is no longer a theoretical subject left to the philosopher and mathematician. Observations can now be made which have a direct bearing on the origin of the universe.

Light leaving the Sun's surface takes about 8½ minutes to reach the Earth. This means that when we look at the Sun, we are not seeing it as it is, but how it looked 8½ minutes ago; or, putting it another way, if the Sun were to suddenly vanish, the

Earth would be bathed in sunlight for 8½ minutes after the event. This effectively means that we are looking back in time by these 8½ minutes. When we observe the planet Jupiter, the light leaving the planet's surface takes 35 minutes to reach the Earth. So we are here again, looking back in time and seeing Jupiter as it was 35 minutes ago. When we move to objects outside the Solar System, the time-lag becomes considerable. Even the closest stars we see are so far away that the light from them takes several years to arrive. Extending this to the external galaxies, the light arriving at the Earth from the Andromeda Galaxy takes some 2¼ million years to get here. In this case we are looking back in time by an enormous period. (This is probably the most distant object in the universe that can be seen with the naked eye – some 150 million million million miles.) Yet this galaxy is one of the closest. By looking farther and farther into space, we are able to examine areas of the universe which are many millions of years old. By comparing the appearances of the universe observed in this way at different times in the past, we should be able to determine how its appearance has changed.

Each of the cosmological theories predicts how the universe should have appeared in the past; and so by comparing these predictions with observed facts, it should be possible to decide which theory is correct. This highlights and explains the astronomer's desire for larger and larger telescopes to delve further and further into the depths of the universe. This enables him to observe objects dating from earlier periods in the history of the universe. It is only by considering the most distant observable galaxies that there is any significant difference in the predictions of the various theories.

In 1960, Baum published a survey of all available results using conventional telescopes. Plots were made of the velocity displacement of spectral lines (the red shift due to the Doppler effect) against the distance of the objects derived from its magnitude or brightness. The most distant objects were 5 thousand million light-years away, just about at the limit observable with conventional telescopes. This is looking back in time by about half the estimated age of the universe (10 thousand million years). The plot is shown in Figure 1.

It can be seen that, although the divergence of the lines is small, the observations do seem to fit the big-bang theory rather better than the steady-state. In fact, the big-bang theory can be made to fit the observations almost exactly if it is assumed that the galaxies redden as they evolve and get older, hence altering their brightness and consequently the estimate of their distance.

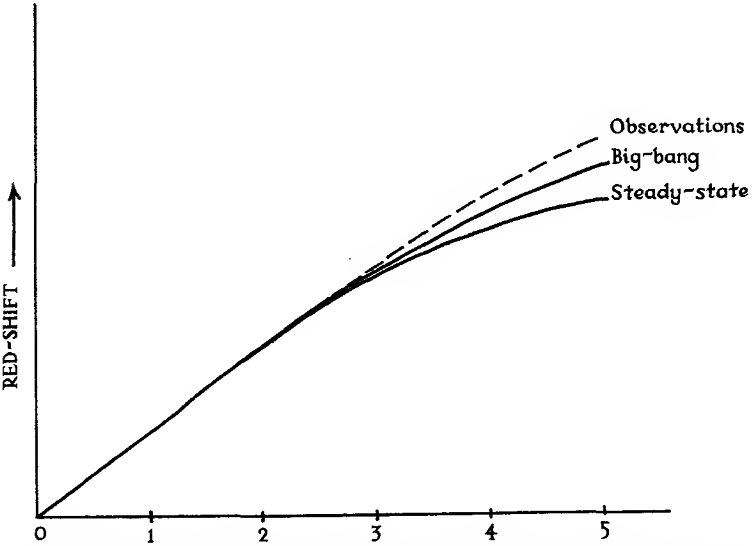

Fig. 1. A simplified diagram showing a comparison between the observations of distant objects using conventional telescopes and the predictions of the big-bang and the steady-state theories.

However, it must be stated that these results were far from conclusive; they only indicated the general trend of observation. It is clear that this was not very satisfactory, and it was at this point that the radio astronomers came to the rescue. By this time, many thousands of radio sources had been discovered, and it had become clear that the radio sources were in general, more distant than the faintest visible galaxies. These should provide a much better test, since they involve looking further back into the history of the universe.

In 1966, Sir Martin Ryle produced counts of radio sources plotted against their power output, and these certainly seemed to indicate that the big-bang theory was correct. The plot is shown in Figure 2.

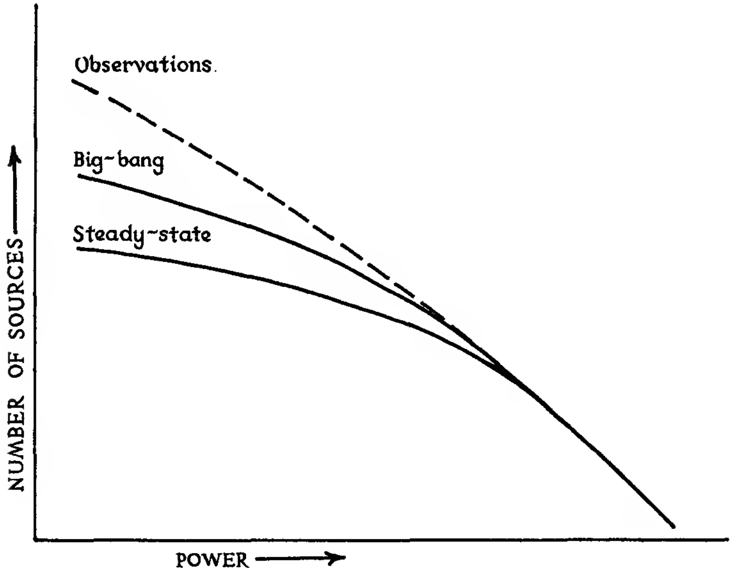

Fig. 2.

The evolutionary effects already described could go a long way to raising the big-bang curve to meet the observations. No such modification is possible in the case of the steady-state theory, and even Hoyle had to admit that things looked grim for his theory. Lately though, some results suggest that the reality of these evolutionary effects is in some doubt.

On the heels of this came a discovery which added to the evidence for the big-bang theory – the background radiation of the sky, regarded as the aftermath of the original big-bang. This would appear as a microwave background radiation with a characteristic temperature which decreases with time. In 1966, this background radiation was measured as 3°K, about that expected on the big-bang theory.

Many astronomers also speculated that a high-temperature big-bang was surely necessary to explain the synthesis of the quite high percentage of heavy elements present in the universe. However, Hoyle has recently shown that in fact, the big-bang would convert mainly hydrogen to helium, with little synthesis of higher elements. This would mean that these higher elements could only have originated by nuclear fusion processes in stars. Unfortunately, even with the age of the universe at 10 thousand million years, it is difficult to explain the synthesis in this way on the big-bang theory, a somewhat longer period is required. No such trouble is encountered with the steady-state theory.

In recent months, Hoyle has raised some sound objections to the radio source data. The difficulty is that cosmologists do not distinguish between various types of radio source, and lump them all together to produce Figure 2. Hoyle has analysed these sources in some detail. Some are normal radio galaxies and gave a slope compatible with the steady-state theory, whilst a mass of objects of doubtful nature give a steep line, and are probably the significant contribution to Ryle's plot. Quasars, another type of object, were until recently the hopeful sources as far as cosmologists were concerned. Their big red-shifts implied that they are at enormous distances, but they are now proving more confusing than helpful. Many astronomers, including Hoyle, believe that a part or perhaps all of the red shift is due to gravitational effects rather than movement.

Quasars are certainly energetic. 3C 273 is known to be less than 10 light-years across, and yet it produces a vast amount of energy every year. If its lifetime is 10,000 years, then its total emitted energy is equivalent to destroying and converting to energy a million times the total mass of our Sun! Quasars emit energy in the infra-red which implies that a mass corresponding to the whole of the Milky Way galaxy is compressed into an object only a few light-years across. Such bodies must have enormous gravitational fields, perhaps leading to gravitational red-shifts. It is clear, though, that although over 300 quasars are now known, it will be impossible to make cosmological deductions from them until we know a lot more about them.

A further piece of evidence against the big-bang theory involves recent calculations about the microwave background radiation already mentioned. Many radio galaxies produce significant amounts of infra-red and microwave emission, and estimates indicate that this source alone is more than enough to explain the 3°K observed value, hence allowing the steady-state theory to fit here. However, the situation has now been changed somewhat. At the end of 1968, results from a high-altitude rocket observing at 0·4–1·3 mm wavelength indicated a background radiation temperature of 7°–10°K, too high for the big-bang theory. The full implications of this result, if correct, have not yet been worked out.

Another startling result at the end of 1968 concerns observations by A. Sandage, on the measurement of the distances of nearby galaxies – the basic distance measurement of cosmology. He finds that the distances of these nearby galaxies are probably in error by a factor of up to two, and they are probably twice as distant as previously thought. This means that the estimated age of the universe must be doubled from 10 to 20 thousand million years, and it means that the difficulty encountered by the big-bang theory in explaining the origin of the heavy elements by stellar burning is removed. The new age estimate allows plenty of time.

One of the problems of the steady-state theory has been to decide how the matter which is created appears on the scene. Does it appear randomly scattered throughout the universe, or in localized areas? The discovery of extremely dense objects in the universe, including the neutron stars, pulsars, quasars, and the nuclei of radio galaxies, offers a possible explanation here. Physics has been hard pushed to explain the energy outputs of these objects, and some believe that the laws of physics as we know them may break down when we deal with these objects. Could these, then, be the sites at which matter is pouring into the universe? It would certainly be a triumph for observational astronomy if the study of these superdense astronomical objects led to a revision and reformulation of the basic laws of physics. Perhaps we ought to, as Hoyle has put it, 'stick to the astronomy, and force the physics to fit'!

It is clear from all this that we are currently passing through a period of considerable confusion. Now that cosmology is an observational science, rather than a decision being possible, there is a mass of conflicting evidence which allows neither the big-bang nor the steady-state theories to be confirmed. The solution of the cosmological problem will be impossible until we can be sure which faint radio sources are in fact at vast distances. Once sophisticated astronomical equipment is orbiting the Earth, and the universe can be viewed over the whole range of wavelengths, the answers to some of our problems should, however, not be too long in coming.

Recent Developments in Astronomy

PATRICK MOORE

The year 1969 will always be remembered as 'the Year of the Moon'. Just before it began, the three astronauts of Apollo 8 – Borman, Lovell, and Anders – made their historic circum-lunar flight. Then, in May 1969, Apollo 10 took Astronauts Stafford, Cernan, and Young on an even more ambitious flight, during which Colonel Stafford and Commander Cernan swooped down to within ten miles of the Sea of Tranquillity. This article is being written in June 1969, and so inevitably it will have been overtaken by the course of events before the *Yearbook* can be published, but as matters stand it seems logical to predict that the first manned-flight to the lunar surface will have taken place before the end of the summer.

Anything of this sort would have seemed out of the question only a few years ago. By now, Dr Paine, at NASA, is seriously talking about sending men to Mars by 1986. The difficulties are immense, but it would be foolhardy to claim that they cannot be overcome in the foreseeable future.

During 1969 further planetary probes were dispatched, both to Venus and to Mars. The two Venus probes were Russian, and seem to have made successful parachute descents through the atmosphere of that decidedly peculiar planet. The high surface temperature has been confirmed, and so has the unexpectedly high atmospheric pressure; carbon dioxide is the main constituent. Following their announcement, the Russians added that Venus is totally inhospitable. This is certainly true; but the inference is that the Russians are now more likely to switch their main attention toward Mars, which is hardly a welcoming kind of world, but is at any rate considerably less menacing than Venus. At the moment we await further information from the U.S.

Mariners 6 and 7, which are due to by-pass Mars during late July and early August 1969. Once again, the preliminary results of these vehicles should be available by the time that the *Yearbook* appears.

All these spectacular results tend to take up one's main attention, but we must always remember that the Solar System is a very small part of the universe as a whole – and that our rocket experiments are limited in range. Physically, we can never hope to reach the systems of other stars, at least by any means known to us at the moment; but there can be little doubt that other planetary systems exist. One case in point is Barnard's Star, a faint Red Dwarf lying a mere 6 light-years from us. Some time ago P. van de Kamp and his colleagues at the Sproul Observatory, in America, announced that minor irregularities in the movement of the star indicated the existence of a massive planet moving round it. Van de Kamp has now improved this result, and believes – with ample justification – that two planets are involved, both more massive than the Earth, but one of which is less massive than Jupiter. Naturally, this is not to infer that either planet is life-bearing – but all the same, the result is immensely significant.

So far as our Galaxy is concerned, a great deal has been heard about the strange, rapidly-vibrating radio sources which are known as pulsars. It is not long since they were discovered, by Jocelyn Bell at Cambridge University; but they have proved to be of exceptional importance. Recent studies of their distances have shown that some of them, at least, are much farther away than was originally thought, which means that they are also more powerful. It was convenient to find that there are two pulsars in the Crab Nebula, because this gives a reliable distance-fix: 4,000 light-years. One of the Crab pulsars has now been identified optically, as a very faint source 'flashing' quickly and reaching the fifteenth magnitude. It has also been established that the pulsars are slowing down gradually in their vibrations, though in a few cases there are apparently random alterations in period which require a great deal of explaining.

Everything now indicates that a pulsar is a neutron star – so dense that a teacupful of its material would weigh around 1,000,000,000 tons. The diameter may be no more than 10 miles, with a temperature no hotter than that of the Sun. If so, then a pulsar represents what must be the final stage in the life of a star; it has evolved from the White Dwarf period. There have been suggestions that pulsars were originally associated with supernova explosions, and this may well be so, particularly in view of the Crab Nebula example – but it is too early to be sure. Also, pulsars may be rather rare in the Galaxy. Only 28 were known at the beginning of 1969.

It is tempting to link pulsars with quasars, since both were originally detected during the 1960s because of their radio emission, but there is no close association. Pulsars, whatever may be their exact nature, belong to our Galaxy. Quasars are external; their spectral Red Shifts indicate immense distances of thousands of millions of light-years, and most astronomers regard them as the most remote and most luminous objects known to us.

During the last I.A.U. Congress, held at Prague in 1967, Sir Martin Ryle suggested that quasars and radio galaxies were merely different evolutionary stages of the same class of object. More recently there has been a suggestion that a quasar may be nothing more than a very remote Seyfert galaxy. A Seyfert galaxy is distinguished by its bright, condensed nucleus and the faintness of its arms, so that if seen over a great distance the arms would not be seen at all. The suggestion has not met with much support, and there is no reason to suppose that any kind of Seyfert galaxy could be as energetic, or as powerful in the radio range, as the quasars appear to be. There remains the nagging doubt that the Red Shifts in the spectra of quasars may not be cosmological, in which case the whole question would be thrown back into the melting-pot. This is extremely improbable, but as yet it cannot be regarded as absolutely impossible.

The next I.A.U. Congress is to be held in August 1970 at Sussex University, Brighton, so that astronomers all over the world will converge there.

PART THREE

For Stellar Observers

Variable Stars for the Binocular-Owner

PATRICK MOORE

Variable star work is one of the most important branches of amateur observation. For many of the stars, large telescopes are of course needed, as was stressed by J. S. Glasby in his article in the 1969 *Yearbook*. However, there are a good many variables which are within range of binoculars – and for some of them binoculars simply have to be used. R Lyræ is a case in point. It is a long way from any suitable comparison star, so that one needs a field of view much wider than can be obtained with any telescope.

Of course, visual estimates with binoculars can hardly be accurate to more than 1/10 of a magnitude. For precision work, photo-electric equipment is needed, and this is beyond the range of the average amateur. But for the long-period and irregular stars, an accuracy of 0·1 magnitude is good enough to be very useful indeed; and these stars are the obvious targets for binocular owners. There is little point in making regular estimates of, say, the Cepheids and the eclipsing binaries, because with these variables it is necessary to have 'photo-electric' accuracy.

Binoculars can be bought in many varieties. A pair of 7 × 50 binoculars (that is to say, a magnification of 7 and an aperture of 50 mm) is useful, and is to be recommended if the observer is to make do with only one pair. I also have a pair of 12 × 60 binoculars, and some powerful 20 × 70 Japanese, which are extremely good but do require 'steadying'. On the whole, I would recommend a magnification of anything between 7 and 12, and, naturally, as large an aperture as the purchaser can afford!

In this article I propose to do no more than indicate some of the binocular variables. There are many others, and anyone who becomes enthusiastic will soon have a list of dozens of them; but it may be helpful to give a few 'specimen cases'. Let us begin with a star which is extremely well known and quite unpredictable: Rho Cassiopeiæ, near Beta Cassiopeiæ in the celebrated W. It is circumpolar from Britain and much of the United States, so that it is always available.

The magnitude range is from 4·1 to 6·2, so far as is known, so that when at 'normal' magnitude it is easily visible with the naked eye. Many observers do in fact make naked-eye estimations of it, though I prefer to use binoculars – with as wide a field as possible. (My 7 × 50 pair is satisfactory, though I also use a pair of Russian 4 × 20.) There are convenient comparison stars, Tau (magnitude 5·1) and Sigma (4·9); Rho lies between them, and cannot be misidentified. Glasby says[1] that the light-curve 'is peculiar in the extreme, consisting of slow waves of varying amplitude and characterized at long, irregular intervals by fairly deep minima'. It was once thought that Rho Cassiopeiæ might be a modified R Coronæ star, but the spectrum – cF5 to cK5 – does not seem to bear this out. The last deep minimum was that of 1946. During 1968 I made over 150 estimates of it, and found

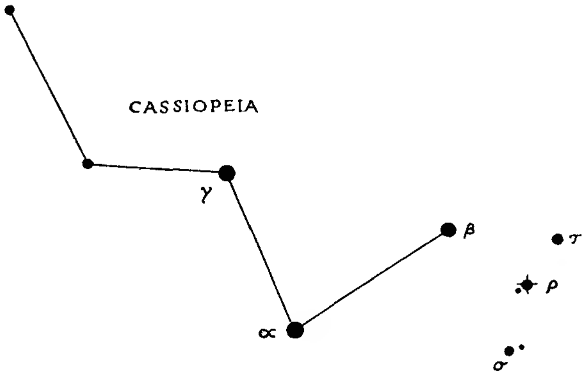

Fig. 1.

that the range was only between 4·6 and 5·2 – but another minimum may begin at any time. Rho is a supergiant, 6,500 light-years away, with a diameter of more than 600,000,000 miles and a mass 25 times that of the Sun.

Another quite irregular star is Mu Cephei – Herschel's 'Garnet Star'. Its discovery – or rather, the discovery of its variability – dates from 1782, and in his famous last-century book G. F. Chambers[2] gave its range as magnitude 3¾ to 6. Whether it ever drops below 5·1 is open to doubt; usually it is rather below magnitude 4. Its neighbour Nu makes a good comparison for it. Binoculars are quite adequate to show up its striking red colour.

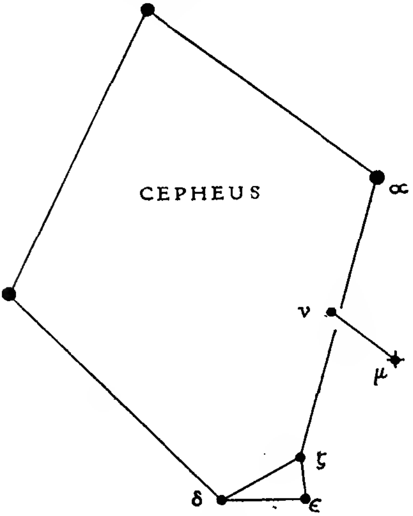

Fig. 2.

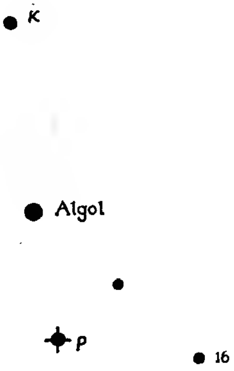

Fig. 3.

Another star which can be followed with the naked eye, but for which very wide-field binoculars are useful, is Rho Persei, close to Algol. The official range is from 3·2 to 4·0, and there is said to be a rough period of between 33 and 55 days,[3] but the period is *very* rough indeed. There are various comparisons; I use a number, of which Kappa Persei (mag. 4·00) is particularly useful.

One star which is remarkably easy to find, and yet not too easy to study, is R Lyræ. It lies not far from Vega, so that from Britain and the northern United States it is always observable at some part of the night. The range is from magnitude 4 to 5; the spectrum is gM6, and the redness is striking even in binoculars.

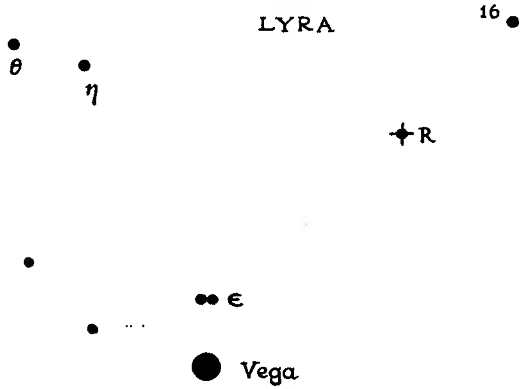

Fig. 4.

The period is given officially as 46 days,[3] though with fluctuations. The trouble about this particular star is the lack of comparisons for it. Eta and Theta Lyræ, both of which are listed as magnitude 4·46, are so distant that they are out of the binocular field except with very low-power instruments; and 16 Lyræ (mag. 5·06), which is closer to R, is generally too faint to be of much use. This may be why visual light-curves tend to be rather erratic; but I suspect that there are many times when the rough period is to all intents and purposes suspended for a while. The variability was discovered by Baxendell in 1855; Chambers, in 1890, gave the period as 46 days and the range from 4 to 4$\frac{3}{4}$.[2]

Let us turn next to R Scuti, below the 'end' of Aquila. It is only 5$\frac{1}{2}$ degrees south of the celestial equator, so that it rises to a satisfactory altitude in our latitudes; the range is from 5·0 to 8·4,[3] and the spectrum ranges between G8 and M3. It is very easy to find. Locate Lambda Aquila, and then sweep down to the famous

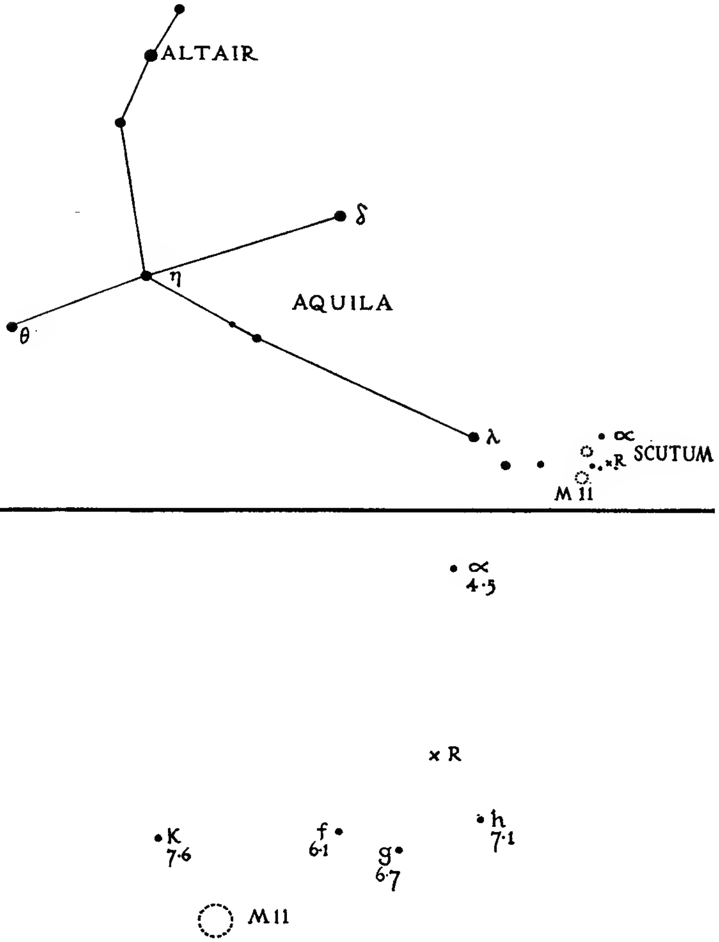

Fig. 5.

open cluster M11, known popularly as the Wild Duck. R Scuti will be found in a characteristic pattern with some convenient comparison stars; there should be no fear of misidentification.

It is an RV Tauri type (more specifically, RVa). There is a rough period of 144 days, and the minima are alternately deep and shallow. However, the light-curve is subject to strong irregularities, and there are periods when all semblance of regularity seems to vanish for a time. R Scuti is particularly worthy of attention, because it is the only RV Tauri star which is ever visible to the naked eye. Again, a fairly wide-field pair of binoculars is needed.

While with the unpredictable stars, let us turn to the celebrated R Coronæ Borealis, in the 'bowl' of the Northern Crown. Anyone who has the slightest knowledge of the sky can find Corona, and in the usual way there is no difficulty in locating R. A chart for it was given by J. S. Glasby in *Planetarium*;[4] in the article he also gave a detailed description and light-curve. It will suffice to say here that the usual magnitude is about 6, but at quite irregular intervals the brilliancy drops down, sometimes to well below 14. If you look at Corona and find that R is an absentee, you may be sure that it is putting on one of its spectacular performances.

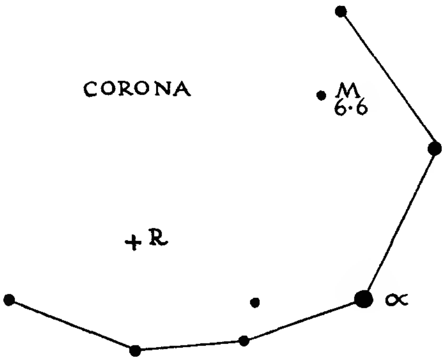

Fig. 6.

There are many long-period variables which are binocular objects when at maximum, but fade down to below binocular range at minimum. One of these is R Leonis, which I am taking as a typical example because it is so easy to find. Sweep from

Regulus, and you will locate the trio made up of R and its two neighbours, 18 Leonis (mag. 5·87) and 19 Leonis (mag. 6·37). During 1970, R will be at its brightest in the spring, and should present no difficulties at all. It was one of the earliest known of its class; its fluctuations were detected by Koch as long ago as 1782, and by now its behaviour is well known. The period is 313 days, and the range from 5·4 to 10·5, so that even when at its dimmest it is still visible in powerful binoculars (though it would be risky to try estimates except with a telescope, unless of course the binoculars are exceptionally large and well mounted).

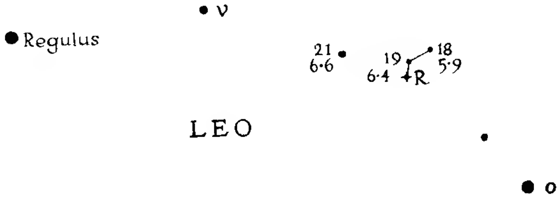

Fig. 7.

Needless to say, R Leonis, like all of its kind, is not perfectly regular, so that it is always worth studying. It is on view all through the late winter, spring, and early summer during convenient times in the evening.

There are several interesting binocular variables in Cygnus, and in particular it is worth noting the long-period star Chi Cygni, whose variability was discovered by G. Kirch in 1686. The period is 407 days, and the range from 3·3 (on rare occasions of exceptional maxima) all the way down to 14·2; the spectrum is of type S. Maximum will occur in the autumn of 1970, and Chi will be easy to find; look near Eta Cygni, which lies between two of the stars in the 'cross' – Gamma, in the centre of the X, and the lovely double Beta Cygni. Near Gamma, too, is P Cygni, which is one of the most remarkable stars in the sky. Like all members of its class, it is intensely luminous, and there is continuous ejection of mass, resulting in a vast, expanding 'atmosphere'. The spectrum is so peculiar that it cannot be put into any recognized type. It was first recorded in 1600 by Jansen, and was classed as a nova; from 1606 it declined, and by 1626 was invisible to the naked eye. From 1654 to 1715 it brightened up from about magnitude 6 to around 5, where it has remained

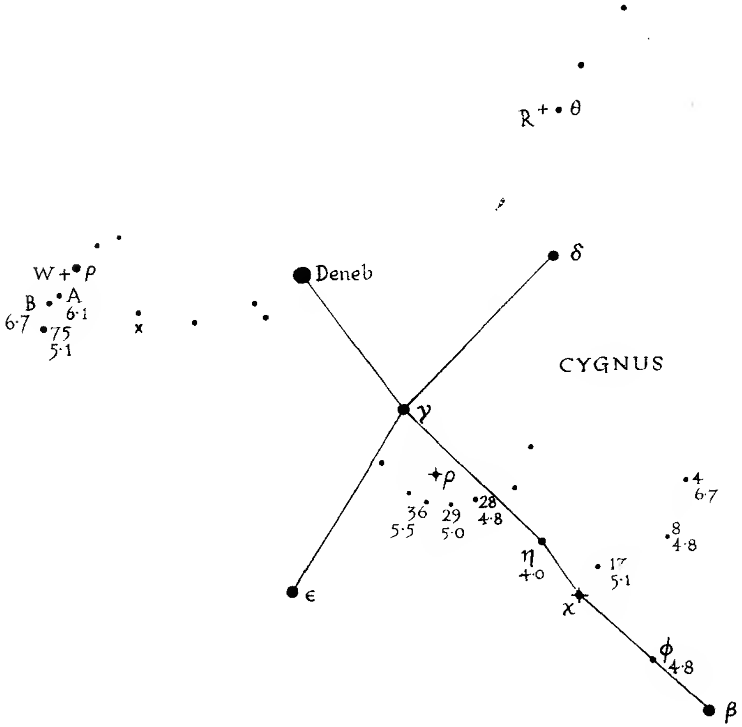

Fig. 8.

ever since, but there are definite fluctuations which may be checked with the comparison stars 28 Cygni (4·82) and 29 (4·98). The field is easy to find, and Gamma Cygni is a guide to it.

An interesting long-period variable is R Cygni, which also is easy to find simply because it lies in the same field as the 4th-magnitude star Theta Cygni. Here we have a period of 426 days, and a large range of from 6·5 to 14·2. Binoculars will show the variable excellently when it is near maximum – as it will be in the spring of 1970 – but when at minimum it is a severe test for my large reflector. For those who locate R when bright and then have the wish and the equipment to follow it through, I give here a chart showing the faint comparison stars in the immediate vicinity – but do not expect to see them with binoculars!

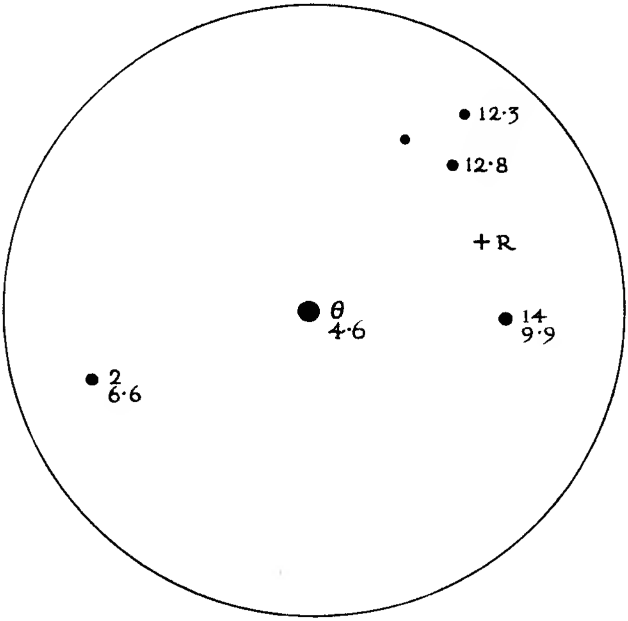

Fig. 9.

Yet another variable in Cygnus is to be found not far from Rho Cygni. This is W Cygni, whose fluctuations were detected by J. E. Gore in 1885 – with a pair of binoculars, let it be added. Chambers[2] in 1890 gave a range of from 5¾ to 7¼ and a period of 126 days, but he qualified this period with a question mark. Atlas Cœli[3] gives 131 days and a range of 5·0 to 7·6, but certainly there are marked irregularities. The field is easy to locate, since

W is a member of a 'chain' of stars stretching from Rho through to the star marked B on the chart given here. A and B are the obvious comparisons – avoid the star marked X on the chart, which is itself variable by more than half a magnitude (though nobody seems to know just what kind of a variable it is; I believe the period, if any, to be short).

Last, but by no means least, I cannot refrain from saying something about Nova Delphini, the star discovered – again by means of binoculars – in 1967 by G. E. D. Alcock. The discovery date was July 8, and the magnitude was 5·6. As Alcock has written,[5] the discovery was the result of a systematic search. Reference can be made to the chart and sequence given in his article;[5] I do not propose to repeat it here, because by necessity I am writing in 1969, and by 1970 the nova may well have faded below binocular visibility. If not, look for it. During the summer of 1969 it was still only just below magnitude 7.

The variables described here are only a few of many, but perhaps some readers may be spurred on to start some observations of them – and others. I have not included naked-eye variables such as Betelgeux, which I have described elsewhere;[6] but in any case, it is evident that useful observations can be carried out with very modest equipment.

References

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3. A. Bečvár. *Atlas Cœli II.* Katalog 1950.0. (Prague, 1964.)
4. J. S. Glasby. 'The R Coronæ Variables'. *Planetarium* (40 Gray's Inn Road, London: Planet Publications), vol. 1, p. 97, June 1968.
5. G. E. D. Alcock. 'Nova Delphini, 1967.' *Planetarium*, vol. 1, p. 35, December 1967.
6. P. Moore. *Naked-Eye Astronomy.* (Lutterworth Press, London, 1967.)

Some Interesting Telescopic Variable Stars

Star	R.A.		Dec.		*Mag. range*	*Period, days*	*Remarks*
	h	*m*	°	′			
R Andromedæ	0	22	+38	18	6·1–14·9	409	
W Andromedæ	2	14	+44	4	6·7–14·5	397	
R Aquilæ	19	4	+ 8	9	5·7–12·0	300	
R Arietis	2	13	+24	50	7·5–13·7	189	
R Aurigæ	5	13	+53	32	6·7–13·7	459	
R Boötis	14	35	+26	57	6·7–12·8	223	
R Cassiopeiæ	23	56	+51	6	5·5–13·0	431	
T Cassiopeiæ	0	20	+55	31	7·3–12·4	445	
T Cephei	21	9	+68	17	5·4–11·0	390	
Omicron Ceti	2	17	− 3	12	2·0–10·1	331	Mira.
R Coronæ Borealis	15	46	+28	18	5·8–14·8	–	Irregular.
W Coronæ Borealis	16	36	+37	55	7·8–14·3	238	
R Cygni	19	35	+50	5	6·5–14·2	426	
U Cygni	20	18	+47	44	6·7–11·4	465	
W Cygni	21	34	+45	9	5·0– 7·6	131	
SS Cygni	21	41	+43	21	8·2–12·1	–	Irregular.
Chi Cygni	19	49	+32	47	3·3–14·2	407	Near Eta.
R Draconis	16	32	+66	52	6·9–13·0	246	
R Geminorum	7	4	+22	47	6·0–14·0	370	
U Geminorum	7	52	+22	8	8·8–14·4	–	Irregular.
S Herculis	16	50	+15	2	7·0–13·8	307	
U Herculis	16	23	+19	0	7·0–13·4	406	
R Hydræ	13	27	−23	1	4·0–10·0	386	
R Leonis	9	45	+11	40	5·4–10·5	313	Near 18, 19.
X Leonis	9	48	+12	7	12·0–15·1	–	Irregular (U Gem type)
R Leporis	4	57	−14	53	5·9–10·5	432	'Crimson star.'
R Lyncis	6	57	+55	24	7·2–14·0	379	
W Lyræ	18	13	+36	39	7·9–13·0	196	
HR Delphini	20	40	+18	58	3·6– ?	–	Nova, 1967.
Nova Vulpeculæ	19	45	+27	2	4·8– ?	–	Nova, 1968.
U Orionis	5	53	+20	10	5·3–12·6	372	
R Pegasi	23	4	+10	16	7·1–13·8	378	
S Persei	2	19	+58	22	7·9–11·1	810	Semi-regular.
R Scuti	18	45	− 5	46	5·0– 8·4	144	
R Serpentis	15	48	+15	17	5·7–14·4	357	
SU Tauri	5	46	+19	3	9·2–16·0	–	Irregular (R CrB type).
R Ursæ Majoris	10	41	+69	2	6·7–13·4	302	
S Ursæ Majoris	12	42	+61	22	7·4–12·3	226	
T Ursæ Majoris	12	34	+59	46	6·6–13·4	257	
S Virginis	13	30	− 6	56	6·3–13·2	380	
R Vulpeculæ	21	2	+23	38	8·1–12·6	137	

Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to be regarded as bona-fide doubles!

Name	*Magnitudes*	*Separation,″*	*Position angle, deg.*	*Remarks*
Gamma Andromedæ	3·0, 5·0	9	060	Yellow, blue. B is again double (0″·4) but needs a larger telescope.
Zeta Aquarii	4·4, 4·6	2·6	291	Becoming more difficult.
Gamma Arietis	4·2, 4·4	8	000	Very easy.
Theta Aurigæ	2·7, 7·2	3	330	Stiff test for 3 in. OG.
Delta Boötis	3·2, 7·4	105	079	Fixed.
Epsilon Boötis	3·0, 6·3	2·8	340	Yellow, blue. Fine pair.
Kappa Boötis	5·1, 7·2	13	237	Easy.
Zeta Cancri	5·6, 6·1	5·6	082	
Iota Cancri	4·4, 6·5	31	307	Easy. Yellow, blue.
Alpha Canum Venat.	3·2, 5·7	20	228	Yellowish, bluish. Easy.
Alpha Capricorni	3·2, 4·2	376	291	Naked-eye pair. Alpha^{2} again double.
Eta Cassiopeiæ	3·7, 7·4	11	298	Creamy, bluish. Easy.
Beta Cephei	3·3, 8·0	14	250	
Delta Cephei	var, 7·5	41	192	Very easy.
Xi Cephei	4·7, 6·5	8	270	Reasonably easy.
Gamma Ceti	3·7, 6·2	3	300	Not too easy
Zeta Coronæ Borealis	4·0, 4·9	6·3	304	
Delta Corvi	3·0, 8·5	24	212	
Beta Cygni	3·0, 5·3	35	055	Yellow, green, Glorious.
61 Cygni	5·3, 5·9	25	150	
Gamma Delphini	4·0, 5·0	10	265	Yellow, greenish. Easy.
Nu Draconis	4·6, 4·6	62	312	Naked-eye pair.
Alpha Geminorum	2·0, 2·8	2	151	Castor. Becoming easier.
Delta Geminorum	3·2, 8·2	6·5	120	
Alpha Herculis	var, 6·1	4·5	110	Red, green.
Delta Herculis	3·0, 7·5	11	208	Optical double.
Zeta Herculis	3·0, 6·5	1·4	300	Fine, rapid binary.
Gamma Leonis	2·6, 3·8	4·3	121	Binary; priod 400 years.
Alpha Lyræ	0·0, 10·5	60	180	Vega. Optical; B faint.
Epsilon Lyræ	4·6, 6·3 4·9, 5·2	3 2·3	005 111	Quadruple. Both pairs separable in 3 in. OG.
Zeta Lyræ	4·2, 5·5	44	150	Fixed. Easy double.
Beta Orionis	0·1, 6·7	9·5	205	Rigel. Can be split with 3 in.
Iota Orionis	3·2, 7·3	11	140	

Name	*Magnitudes*	*Separation,″*	*Position angle, deg.*	*Remarks*
Theta Orionis	6·0, 7·0 7·5, 8·0			The famous Trapezium in M.42.
Sigma Orionis	4·0, 7·0 7·5, 10·0	11·1 12·9	236 085	Quadruple. D is rather faint in small apertures.
Zeta Orionis	1·9, 5·0	3	160	
Eta Persei	4·0, 8·5	8·5	300	Yellow, bluish.
Alpha Piscium	4·3, 5·3	1·9	291	
Alpha Scorpii	0·9, 6·8	3	275	Antares. Red, green.
Nu Scorpii	4·2, 6·5	42	336	
Theta Serpentis	4·1, 4·1	23	103	Very easy.
Alpha Tauri	0·8, 11·2	130	032	Aldebaran. Wide, but B is very faint in small telescopes.
Zeta Ursæ Majoris	2·3, 4·2	14·5	150	Mizar. Very easy. Naked-eye pair with Alcor.
Alpha Ursæ Minoris	2·0, 9·0	18·3	217	Polaris. Can be seen with 3 in.
Gamma Virginis	3·6, 3·7	4·8	305	Binary; period 180 yrs. Closing.
Theta Virginis	4·0, 9·0	7	340	Not too easy.

Some Interesting Clusters and Nebulae

Object	R.A.		Dec.		*Remarks*
	h	*m*	°	′	
M.31 Andromedæ	00	40·7	+41	05	Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41·3	+61	36	Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31·8	+30	28	Spiral. Difficult with small apertures.
H.VI 33–4 Persei	02	18·3	+56	59	Double cluster; Sword-handle.
M.1 Tauri	05	32·3	+22	00	Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33·4	−05	24	Great Nebula, Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06·5	+24	21	Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30·7	+04	53	Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45·5	−20	42	Open cluster, just visible to naked eye.
M.44 Cancri	08	38	+20	07	Præsepe. Open cluster near Delta Cancri. Visible to naked eye.
M.97 Ursæ Majoris	11	12·6	+55	13	Owl Nebula, diameter 3′. Planetary.
M.3 Canum Venaticorum	13	40·6	+28	34	Bright globular.
M.80 Scorpionis	16	14·9	−22	53	Globular, between Antares and Beta Scorpionis.
M.4 Scorpionis	16	21·5	−26	26	Open cluster close to Antares.
M.13 Herculis	16	40	+36	31	Globular. Just visible to naked eye.
M.92 Herculis	17	16·1	+43	11	Globular. Between Iota and Eta Herculis.
M.7 Scorpionis	17	51·6	−34	48	Fine open cluster. Very low in England.
M.23 Sagittarii	17	54·8	−19	01	Open cluster nearly 50′ in diameter.
H.VI 37 Draconis	17	58·6	+66	38	Bright planetary.
M.8 Sagittarii	18	01·4	−24	23	Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10·9	+06	50	Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18·8	−16	12	Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49·0	−06	19	Wild Duck. Bright open cluster.
M.57 Lyræ	18	52·6	+32	59	Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58·1	+22	37	Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02·1	−11	31	Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28·3	+12	01	Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31·0	+48	17	Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

PART FOUR

Miscellaneous

Some Recent Books

Old and New Astronomy, by E. A. Beet (Bell, 1967). An excellent general introduction, suited both to school-age and older readers.

Life, Mind and Galaxies, by V. A. Firsoff (Oliver & Boyd, 1968). A survey of the problem of life beyond the Earth, with some original contributions by the author.

The Amateur Astronomer's Lunar Photographic Atlas, by Henry Hatfield (Lutterworth, 1968). A full atlas of the Moon, with a long series of first-class photographs covering the entire surface, together with a complete map. The lunar observer will find it invaluable.

Quasars, by F. Kuhn and H. Palmer (Manchester University Press, 1968). A semi-technical but mainly non-mathematical introduction to quasars, excellently written by two leading experts in this field of research.

Suns, Myths and Men, by Patrick Moore (Muller, 1969). An outline of changing views of the universe, with a look into the future, and with some highly controversial opinions.

The Old Moon and the New, by V. A. Firsoff, with a postscript by Patrick Moore (Sidgwick and Jackson, 1969). A review of the latest discoveries about the moon with excellent photographs.

Their Majestie's Astronomers, by C. A. Ronan (Bodley Head,1968). A survey of British astronomy from its beginnings to the present time, written in the author's usual informative style. Highly recommended.

The Penguin Dictionary of Astronomy, by Åke Wallenquist (Penguin, 1968). A useful, concise dictionary of astronomical terms by a leading Swedish astronomer, well translated and well presented.

Our Contributors

Dr Joseph Ashbrook is Editor of the world-wide astronomical periodical *Sky and Telescope.* He will need no introduction; suffice to say that one of his particular interests is in the history of astronomy. He lives in Weston, Massachusetts, some miles from Cambridge.

Henry Brinton is one of our regular contributors; he lives at Selsey in Sussex, and divides his time between writing, astronomy, and his social work, which is concerned largely with the Regional Hospital Board.

Commander H. R. Hatfield, R.N. is a serving officer in the Royal Navy, and is known as an expert in marine surveying. In the astronomical world he is renowned as a photographer, and he has published many papers as well as his Lunar Atlas. He is a member of the Council of the British Astronomical Association, and has a private observatory at his home in Sevenoaks.

Keith Hindley, B.Sc., F.R.A.S., is Director of the Meteor Section of the British Astronomical Association. His astronomical interests are wide, and he is the author of many papers. He is at the Robert Robinson Laboratories of the University of Liverpool. Throughout much of 1970 he will be carrying out research in America.

Dr R. C. Maddison, B.Sc., F.R.A.S., Lecturer in Physics at the University of Keele, is also in charge of the University's astronomical observatory; he is an expert upon electronic aids in astronomy. He is also Director of the Lunar Section of the British Astronomical Association, and is a well-known lecturer and broadcaster.

Howard Miles, M.Sc., F.R.A.S., is Director of the Artificial Satellite Section of the British Astronomical Association, and Lecturer in Mathematics at the Lanchester College of Technology, Coventry. He, too, is one of our most regular and valued contributors.

Astronomical Societies

The advantage of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1966 *Yearbook*; a condensed list, suitably brought up to date, is given below.

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
British Astronomical Association	303 Bath Road, Hounslow West, Middlesex (Miss Lydia A. Brown)	45*s* (§30*s*)	Burlington House, Piccadilly Last Wed. each month (Oct-June)
Irish Astronomical Society:			
Belfast Centre	35 Ardenvohr Road, Belfast (D. Beesley)	20*s* (§10*s*)	Fortnightly, Queen's University, Belfast
Dublin Centre	St Fintan's Cottage, Carrickbrack Road, Sutton, County Dublin (F. Murphy)	20*s* (§10*s*)	Fortnightly University College, Earlsfield Terrace, Dublin
Armagh Centre	The Royal School, Armagh (J. Perrott)	20*s* (§5*s*)	Monthly The Planetarium, Armagh
North-West Centre	Magee University College, Londonderry (Professor W. J. Guthrie)		
Junior Astronomical Society	17 Chanctonbury Chase, Redhill, Surrey (D. Beglan)	15*s*	Caxton Hall, London, S.W.1 Quarterly
Altrincham and District Astronomical Society	33 Edale Grove, Sale, Cheshire (F. W. Talbot)	5*s*	Park Road Library, Timperley 3rd Friday of each month
Aylesbury Astronomical Society	9 Elm Close, Butler's Cross, Aylesbury (N. Neale)	20*s*	As arranged
Birmingham Astronomical Society	17 Hannafore Road, Edgbaston, (W. E. Marsh)	20*s* (§5*s*)	Birmingham and Midland Institute Monthly
Bristol Astronomical Society	10 Sherbourne Street, St. George, Bristol 5 (S. J. Brewer)	20*s*	Lecture Theatre, Bristol University 3rd Friday each month, Sept.-May
Caithness and Dounreay Astronomical Society	Room 31, Ormlie Lodge, Thurso, Scotland (Miss M. J. A. Clark)	20*s*	Fortnightly
Cambrian Astronomical Society	43 Heol Chappell, Whitchurch, Cardiff (G. Stokes)	15*s* (§7*s* 6*d*)	Every 3rd week, 7.30. 38 Park Place, Cardiff
Cambridge Astronomical Society	5 Haggis Gap, Fulbourn (S. R. Whistler)	21*s* (§7*s* 6*d*)	7 Brooklands Avenue, Cambridge 2nd Mon. each month, Oct.–July

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
Chester Society of Natural Science, Literature and Art	8 Guy Lane, Waverton, nr. Chester (Mrs N. Hoskyns)	—	Grosvenor Museum, Chester Fortnightly
Chesterfield Astronomical Society	Hilltop Cottage, Gallery Lane, Holymoorside, Chesterfield (Mrs R. C. Naylor)	20*s* (§10*s*)	Barnett Observatory Newbold Each Friday
Clackmannanshire Astronomical Society	9 Deer Park, Sauchie, Alloa (J. Cluckie)	20*s*	St Mary's School, Alloa. Monthly, 3rd Friday Sept.–May
Crawley Astronomical Society	Crawley College of Further Education, Sussex (F. D. Cooper)	7*s* 6*d*	Crawley College of Further Education Monthly
Crayford Manor House Astronomical Society	Manor House Centre, Crayford, Kent (R. H. Chambers)	None	Manor House Centre, Crayford Monthly during term-time
Dundee Astronomical Society	4 Finlaggan Place, Dundee Scotland (D. Gavine)	10*s* (§5*s*)	Mill's Observatory Dundee Fortnightly in the winter
Eastbourne Astronomical Society	80 Ringwood Road, Eastbourne, Sussex (W. O. Tutt)	21*s* (§10*s* 6*d*)	As arranged Monthly
East Lancashire Astronomical Society	95 Accrington Road, Blackburn (L. Willan)	20*s* (§7*s* 6*d*)	Longridge Observatory Preston
Astronomical Society of Edinburgh	126 W. Saville Terrace, Edinburgh 9, Scotland (N. G. Matthew)	20*s*	Calton Hill Observatory Edinburgh Monthly
Ewell Astronomical Society	11 Elmwood Drive, Ewell, Surrey (J. Bentley)	20*s* (§10*s*)	Pitt House, Ewell, Surrey 2nd Tuesday of each month
Fellowship of Junior Astronomers, Edinburgh	58 Ogilvie Terrace, Edinburgh 11, Scotland (Miss Edith McLean)	7*s* 6*d*	Calton Hill Observatory Edinburgh 2nd Sat. each month, Sept.–June
Fylde Astronomical Society	115 Abercrombie Road, Fleetwood, Lancs (P. P. Cuffe)	10*s* (§5*s*)	Nautical College, Fleetwood 1st Thursday of each month, Sept.–May inclusive
Astronomical Society of Glasgow	164 Mugdock Road, Milngavie, Glasgow, Scotland (N. M. Orr)	10*s*	Roy. Coll. Science and Tech., Glasgow 3rd Thur. each month, Sept.–April
Herschel Society	35 Kendal Drive, Slough (C. Wise)	—	(To be announced)
Leeds Astronomical Society	Maths. Dept., The University, Leeds 2 (B. L. Meek)	10*s* (§5*s*)	Leeds University Six annually
Leicester Astronomical Society	120 Airsdale Road, Leicester (L. D. Gregson)	30*s* (§12*s* 6*d*)	Leicester Museum and Art Gallery Monthly
Lincoln Astronomical Society	344 Brant Road, Lincoln (P. Hammerton)	20*s* (§5*s*)	Lincoln YMCA Hall 1st Tue. each month

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
Liverpool Astronomical Society	135 St Michael's Road, Great Crosby, Liverpool 23 (J. E. Abrahams)	15*s* (§5*s*)	Royal Institution, Liverpool Monthly
Maidenhead Astronomy Group	129 Fane Way, Maidenhead, Berkshire (S. A. H. Roper)	10*s* (§2*s* 6*s*)	Maidenhead Grammar School Once every 3 weeks
Manchester Astronomical Society	Cragside, Cliff Avenue, Summerseat, Bury (Alan Whittaker)	20*s* (§10*s*)	Godlee Observatory, Manchester 1 Weekly
Newcastle-on-Tyne Astronomical Society	30 Kew Gardens, Whitley Bay, Northumberland (G. E. Manville)	20*s*	Botany Lecture Theatre Newcastle University Monthly, Sept.–April
Nottingham Astronomical Society	18 Naseby Close, Heathfield, Nottingham (C. Swift)	25*s*	Monthly
Oxshott Astronomical Group	Norman Cottage, Pond Piece, Sheath Lane, Oxshott, Surrey (E. H. Noon)	10*s*	Oxshott Village Centre 1st Wed. each month Sept.–May
Paisley Astronomical Society	14 Cheviot Avenue, Barrhead, Glasgow (Mrs J. Holms)	20*s* (full), 10*s* (associate) (half subscription for those under 21)	Coats Observatoyr, 49 Oakshaw Street, Paisley Monthly
Plymouth Astronomical Society	5 Woodside, Lipson, Plymouth (Lawrence Harris)		Plymouth College of Technology, Tavistock Road, Plymouth Monthly
Portsmouth Astronomical Society	52 Denbigh Drive, Fareham, Hampshire (S. W. Hackman)	—	(To be announced)
Preston and District Astronomical Society	35 Bispham Road, Carleton, Poulton-le-Fylde, Lancs (C. Lynch)	20*s* (§5*s*)	Chamber of Commerce, 49a Fishergate, Preston 3rd Mon. each month Sept.–May
Salisbury Plain Astronomical Society	St George's Cottage Orcheston Salisbury, Wilts. (R. J. D. Nias)	10*s* (§5*s*)	St George's Rectory, Orcheston Quarterly
Sidereal Society	Flat 2, 11 Wellington Road, Brighton, Sussex (Mrs M. L. Cohen)	20*s* (§10*s*)	6 Brunswick Terrace, Hove, Sussex Each Wed., 730–9.30
Slough Astronomical Society	The Elms, Odds Farm, Green Common Lane, Wooburn Common, High Wycombe, Bucks (E. Shilton)	20*s*	Monthly
Southampton Astronomical Society	13 Luccombe Place, Shirley, Southampton (F. G. H. Cunningham)	20*s* (§10*s*)	Polygon Hotel, Southampton 2nd Thur. each month Sept.–May
Stoke-on-Trent Astronomical Society	19 Engelsea Avenue, Weston Coyney, Stoke (T. F. Stringer)	20*s*	Henley, near Stoke-on-Trent Monthly
Swansea Astronomical Society	77 Craiglwyd Road, Cockett, Swansea (R. E. Roberts)	20*s*	As arranged
Torbay Astronomical Society	4 Heath Rise, Brixham, Devon (Miss A. Longman)	15*s* (§5*s*)	Quay Tor Hotel, Scarborough Road, Torquay Monthly

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
Waltham Forest and District Junior Astronomy Club	24 Fulbourne Road, Walthamstow, London E17 (B. Crawford)	10*s*	24 Fulbourne Road, Walthamstow, London E17 Fortnightly (Mondays)
Warrington Astronomical Society	2 Dale Avenue, Appleton, Warrington (B. P. Rees)	20*s*	Central Library, Museum Street, Warrington, Lancs Monthly, Sept.–May
Warwickshire Astronomical Society	20 Humber Road, Coventry, Warwickshire (R. D. Wood)	80*s*	20 Humber Road, Coventry Each Tuesday
Wolverhampton Astronomical Society	Garwick, 8 Holme Mill, Fordhouses, Wolverhampton (M. Astley)	20*s*	38 Tettenhall Road, Wolverhampton Alternate Mon., Sept.–April
West London Astronomical Society	46 Vista Way, Harrow, Middlesex (P. Macdonald)	3*s* 6*d*	Monthly (Venue to be announced)
Wyvern Astronomical Society	2 Howcroft, Churchdown, Gloucester (A. F. Edwards)	15*s* (§5*s*)	Clubhouse, Churcham Last Friday of each month except Aug.
York Astronomical Society	97 Carr Lane, Acomb, York (R. Emmerson)	20*s* (§5*s*)	As arranged Monthly, Sept.–May
Thanet Astronomical Society for Youth	Woodlands, Fair Street, Broadstairs, Kent (Paul Sutherland)	5*s*	Hilderstone House, Broadstairs, Kent Monthly
Chelmsford and District Astronomical Society	57 Hampton Road, Great Baddow, Chelmsford (N. Moorcroft)	20*s* (OAPs and under 18s 10*s*)	Civic Centre, Chelmsford, Last Friday in each month

It is possible that this list of local societies may not be quite complete. If any have been omitted, the secretaries concerned are invited to write to the Editor (c/o Messrs Sidgwick & Jackson (Publishers), Ltd, 1 Tavistock Chambers, Bloomsbury Way, London WC1), so that the relevant notes may be included in the 1971 *Yearbook*.

Sidgwick & Jackson
Books on
Astronomy and Space

The History of Astronomy, by Giorgio Abetti
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A comprehensive guide for the general reader of scientific tastes . . . magnificent celestial photographs. *Illustrated* 30s

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Exploring the Planets, by V. A. Firsoff
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Facing the Universe, by V. A. Firsoff
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Re-examines and re-assesses previous conceptions in the light of the latest space explorations. *Illustrated* approx. 50s

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